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ASRDI OXYGEN TECHNOLOGY SURVEY

Volume II: Cleaning Requirements, Procedures, and Verification Techniques

By H. Bankaitis and Carl F. Schueller

Aerospace Safety Research and Data Institute
Lewis Research Center, Cleveland, Ohio

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PREFACE

This document is one of a series of publications developed by the Aerospace Safety Research and Data Institute for use as oxygen system design and operation guidelines. The material presented herein is a survey of oxygen technology dealing with cleaning requirements, procedures, and verification techniques. It documents the different levels of hardware cleanliness requirements as functions of the particular oxygen service application, the cleaning methods used to attain the required degree of cleanliness, and the verification techniques presently practiced to establish that the cleanliness level required has been attained. No attempt is made to select recommended cleaning procedures since a basis for such selection is not now available.

This report includes an appendix which presents abstracts of the cleaning methods reviewed for this survey. Furthermore, a microfiche supplement of references is attached inside the back cover to make pertinent pages of listed references readily available to the reader. Some references are included in their entirety, while only selected pages or sections of others are reproduced. The location of each reference in the supplement is noted in the list of references.

The following representative at the NASA centers participated in the critical review of the text: Haggai Cohen and Thomas Kerr of NASA Headquarters; Melvin G. Olsen of Kennedy Space Center; Leslie W. Ball and personnel of the Science and Engineering Directorate of Marshall Space Flight Center; Bernard I. Sather and Frank E. Belles of Lewis Research Center; G. Hennings and J. W. Gibb of Plum Brook Station; and specialists in the Quality Assurance Office and the Engineering and Development Directorate of Manned Space Center.

I. Irving Pinkel, Director
Aerospace Safety Research and Data Institute
National Aeronautics and Space Administration

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INTRODUCTION

Cleanliness requirements for mechanical systems have been undergoing a continuous evolution. With the advent of the airplane hydraulic and pneumatic systems and their associated close tolerances, special requirements had to be instituted to prevent malfunction or excessive wear due to particulate matter or contaminants. When man prepared to venture into the hostile environment of space more stringent requirements were necessary. With the more recent widespread use of oxygen, both in industry and space, additional scope had to be added to the cleanliness requirements. Recognition of oxygen's inherent reactivity characteristic as well as the fact that relatively small quantities of contaminants could serve as ignition sources and thus cause the burning of otherwise satisfactory containment materials led to these necessary additional requirements.

During this evolution a proliferation of cleanliness requirements has been generated. In part, this has occurred because the applications vary in scope from industrial use, with the least stringent requirements, to manned space vehicles, with the most demanding requirements. It has also been caused by the fact that the actual degree of cleanliness required has a small scientific base. Thus, many groups in both industry and government have generated cleaning specifications by trial and have verified them by operating experience accumulated with particular applications.

This report displays the oxygen system cleaning specifications drawn from 23 industrial and government sources, cleaning processes employed for meeting these specifications, and recommended postcleaning inspection procedures for establishing the cleanliness achieved.

It is the purpose of this document to collate and examine areas of agreement and difference in the specifications, procedures, and inspection. Also, the lack of clarity or specificity will be discussed. This absence of clarity represents potential safety hazards due to misinterpretation. Also, it can result in exorbitant expenditures of time and money in satisfying unnecessary requirements.

CLEANLINESS REQUIREMENTS

The degree of required cleanliness depends on the intended application of the component or system and is usually expressed in terms of allowable limits of contaminants. A contaminant is defined as any material which by being present in a system or component may cause mechanical malfunction, fire, or explosion. The types of most common contaminants and their relative sizes are illustrated in figure 1 (ref. 1). Techniques

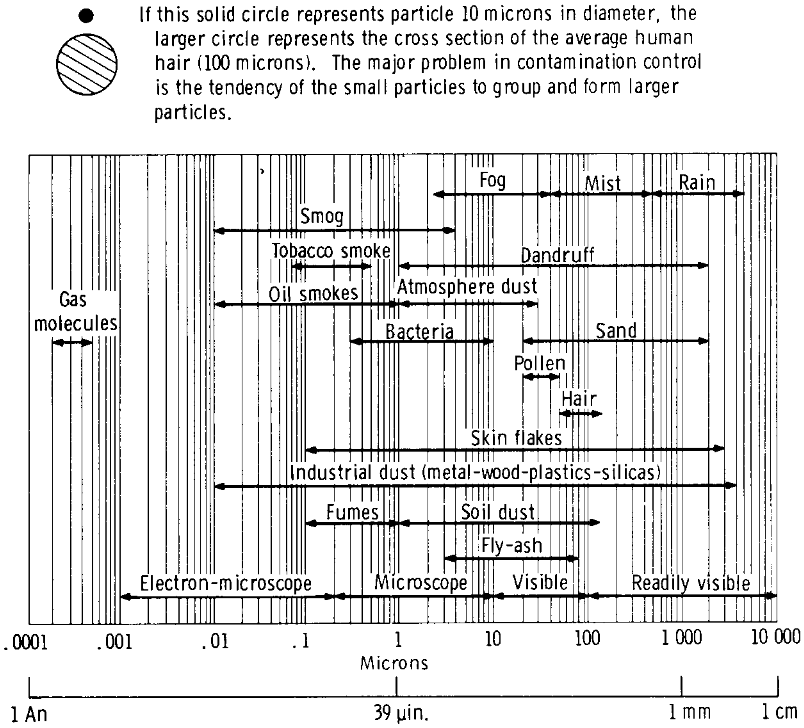

Figure 1. - Approximate sizes of common particles (ref. 1).

required to detect these contaminants as a function of their size are also indicated. Sources of contaminants which are probably the most difficult to predict are the fabrication and assembly operations such as grinding, cutting, welding, etc. Effective cleaning will

(1) Prevent functional interference with components by particles deposited on moving parts, valve seats, and system sensors and controls

(2) Reduce the likelihood of fire by rubbing friction which might occur if the clearance between moving system parts fills with contaminants

(3) Avoid accumulations of finely divided contaminants which are more easily ignited in oxygen than the bulk system materials

The cleanliness requirements can be placed in the following two general categories:

(1) Aerospace clean - applies to flight systems, components, ground service equipment for flight systems, environmental chambers, space cabins, and breathing apparatuses.

(2) Commercial clean - applies to industrial and process systems in which the threat, or consequences, of failure are low.

Wherever possible, the specifications, cleaning processes, and verification procedures are grouped in this report according to these cleanliness grades. Unfortunately, the originators of the cleaning requirements seldom classified them according to this scheme, but this pattern is discernible in the accumulated cleaning information.

Description of Contaminants

The following five contaminants are mentioned in the 33 cleanliness requirements (refs. 2 to 22) reviewed:

(1) Particulate matter - general term applied to finely divided solid matter of dimensions measured in microns (10^{-6} m or 3.9×10^{-5} in.). Its population in a system (or component) is determined by counting the particles in a unit volume of wash fluid (liquid or gas) that passed through the system at the end of the cleaning process. The cleanliness of the system (or components) is reported in terms of the number of particles of a given size range per unit area of the surface rinsed or washed. If the internal surfaces are accessible after cleaning, then the particle count can be made from a wipe of the surface and reported on the basis of the particle distribution per unit area of the internal system surface.

(2) Fiber - particle having a length of 100 microns or greater with a length to width ratio of 10:1 or greater. Fibers are classed according to length in microns and reported as a population number per square foot of internal surface area. (The internal surface which is exposed to the service media is often referred to in the literature as the "critical surface area.")

(3) Condensable hydrocarbons - usually refers to hydrocarbons capable of going from a gaseous to a liquid or solid state at system temperature and pressure. They are measured and reported as parts per million by weight of system fluid. In chemical use it usually refers to 1 microgram per gram.

(4) Solvent soluble organic residue - usually refers to hydrocarbons remaining on a surface after cleaning. It is measured in milligrams per milliliter of rinse solvent and reported in milligrams per square foot of critical surface area.

(5) Total solids - constitute the sum total of solid material obtained by filtering and evaporating a unit volume of the cleaning solvent. Total solids are reported in units of weight per unit area of the system or component.

Cleanliness Requirements for Particulate Matter Contaminants

In the reviewed cleanliness requirements particulate matter is given the greatest emphasis. The cleanliness requirements listed in table I (pp. 63 to 66) show considerable variation in the specification for particulate cleanliness. In some cases acceptable particle sizes and population are small and carefully defined; in other cases only the population of the largest acceptable sizes are specified. The differences are suspected to relate to the clearance dimensions of the moving parts of the system of concern when the specifications were first prepared. Permissible particle sizes are kept well below these clearance dimensions. Also, it is desirable to point out that generally the smallest particles have the tendency to group and form larger particles. However, if they do not agglomerate and become suspended in the wash fluid, they are most easily washed from the system since the smallest particles are more readily maintained suspended in the wash fluid. Removal of the smallest particles from the surface becomes increasingly less effective as particle size decreases because of their ability to tenaciously adhere to the surface. This adherence is further enhanced by the wetting action of the wash fluid through the formation of residual film and corresponding surface tension. Any attempt to remove the particle must overcome this surface tension. By placing an upper limit on the permissible size and population of the larger particles, one is reasonably assured that the population of smaller particles will not be troublesome. The designer must judge the range of permissible particle sizes remaining in his system after cleaning on the basis of the sensitivity of the system components to interference by particles (ref. 23). It might be noted that past experience (described in the proposed Lewis Research Center design criteria monograph on liquid rocket valve assemblies) indicates that the particle size should be restricted to one-eighth of the clearances available. Furthermore, a John F. Kennedy Space Center (KSC) study of cleanliness specification (ref. 24, p. 26) states that for a given cleanliness level a standard particle distribution can be calculated per MIL-STD-1246A to obtain the total particle volume. This calculated volume used in conjunction with the available clearance can then be related to the allowable particulate contamination level and thus the degree of cleanliness required for the system. The pore size of the filters that can be used to protect these components and the ignition hazard posed by cavities in the system where particles may drop out of suspension in the process fluid and form dangerous accumulations must also be taken into consideration. The particulate specifications given in table I have served successfully for the systems indicated. The designer may use the one which comes closest to matching his system.

Overall cleanliness requirements for manned and unmanned space flight hardware systems (tanks, pipes, propulsion units, etc.) are presented in figure 2. The particle cleanliness requirements for manned space flight hardware are inconclusive for particles smaller than 175 microns. For unmanned ballistic flight systems these requirements are inconclusive for particles smaller than 300 microns. However, the limits of the largest allowable size of contaminants are very specific: 1000 microns for unmanned ballistic flight systems, and 2500 microns for systems used in manned space flight applications. According to KSC personnel, the largest allowable size of contaminant acceptable for manned space flight applications derived from actual "field tests" at the KSC complexes represents the maximum cleanliness results obtainable in the field during the 1960 to 1964 time period.

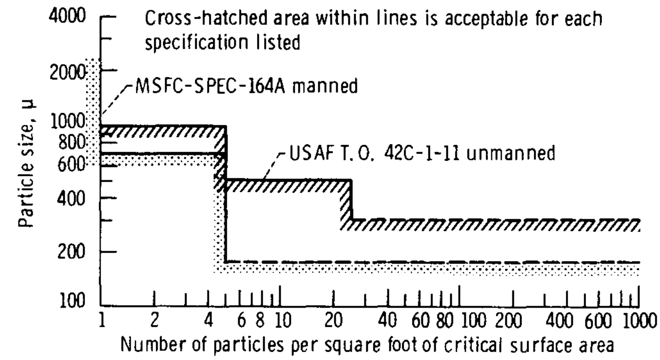

Figure 2. - Particulate matter - cleanliness requirements for space hardware.

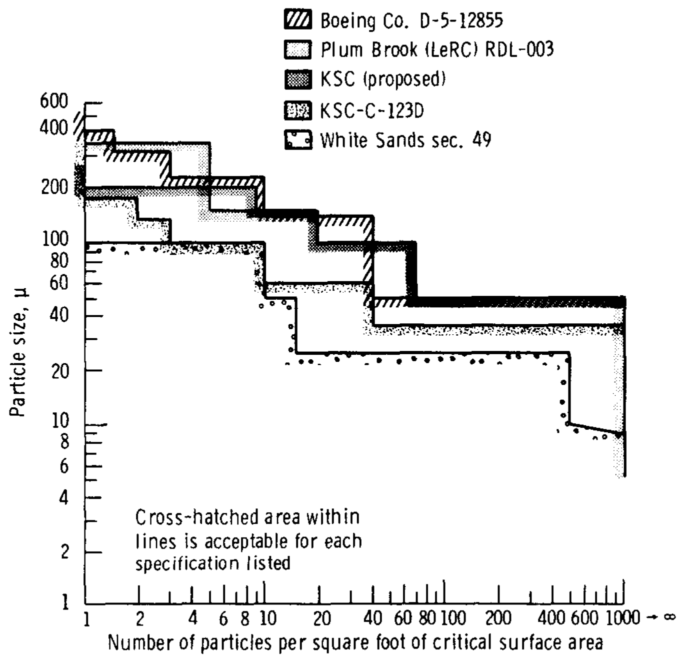

Figure 3. - Particulate matter - cleanliness requirements for ground based components and systems that may interface with flight systems.

Figure 3 shows the particulate cleanliness requirements for systems in the fabrication phase or test apparatus operations. Some of the systems in fabrication may be interfaced with space flight hardware or may be ground support equipment for space flight hardware. In the latter case the contaminant control is a very significant part of operations because of the extensive reuse of the equipment and the associated hazard of contaminant accumulation. In comparison to space flight systems cleanliness requirements, the requirements for ground service equipment illustrated in figure 3 allow fewer larger size particulate matter contaminants. Reasons for this are not readily obvious from the available literature. A comparison of the KSC-C-123D (ref. 10) cleanliness requirements with the KSC proposed cleanliness requirements (ref. 11) indicates that the cleanliness requirements may be relaxed somewhat.

Figure 4 shows the particulate cleanliness requirements for environmental chambers, space cabins, and breathing oxygen components. The wide spread in allowable population of particulate matter is emphasized. However, this may be understandable because more contaminants must be accommodated by the design because man is a source of contamination in these cases. Rationale for abrupt changes in permitted size of population of particulate matter could not be established from the available literature.

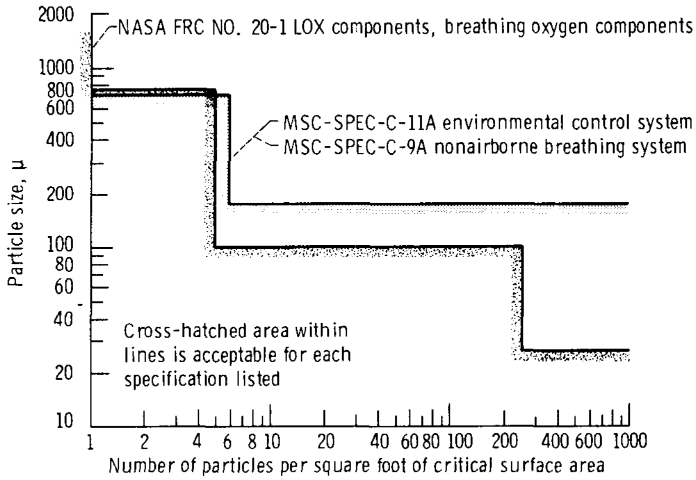

Figure 4. - Particulate matter - cleanliness requirements for space cabins, environmental chambers, breathing oxygen components.

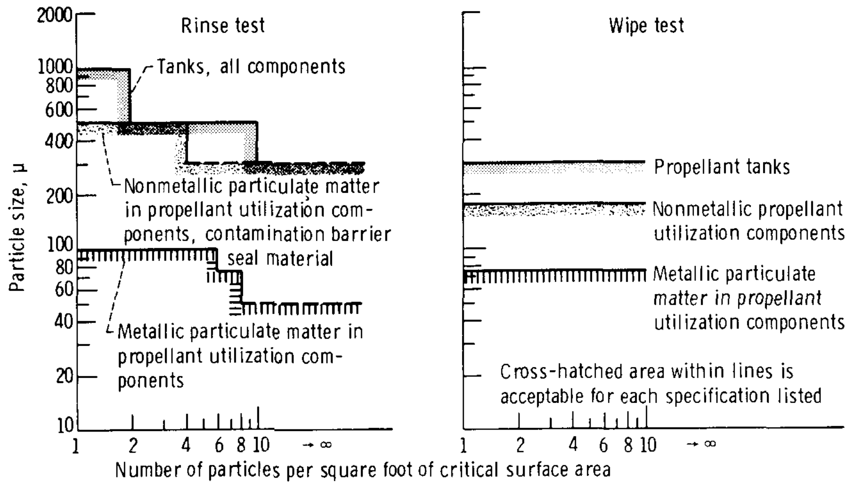

Figure 5. - Particulate matter - cleanliness requirements as function of material and inspection technique (spec. 075192B GDA-Convair, Dec. 13, 1967).

Figure 5 presents particulate cleanliness requirements specified by General Dynamics - Convair Division (ref. 19). The outstanding feature of these requirements is the classification of cleanliness requirements according to cleanliness verification techniques and the nature of the contaminant. The cleanliness requirements are more stringent for metallic particles than for nonmetallic regardless of verification techniques used.

Figure 6 is an example of the particulate cleanliness requirements established by commercial industry engaged in oxygen production. Three distinct classes of cleaning requirements are defined:

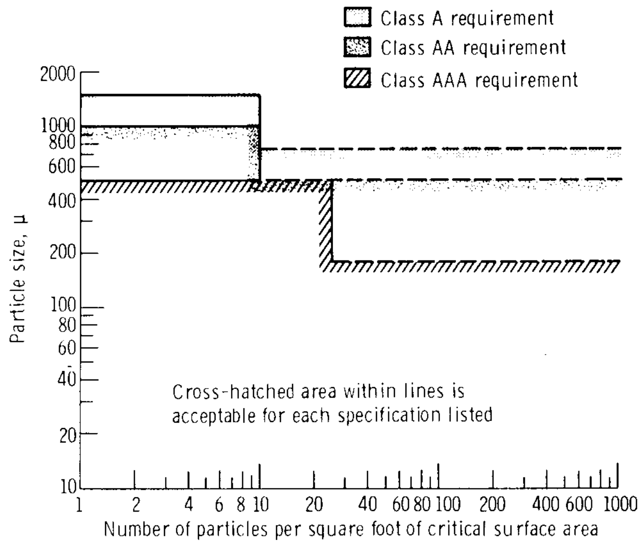

Figure 6. - Pariculate matter - air products and chemicals cleanliness requirements.

(1) Class AAA is the most demanding class of cleanliness requirements; it is applicable to equipment or apparatus with moving surfaces which contact liquid or gaseous oxygen. In relation to the government and aerospace industry cleanliness requirements, this class is within the general space flight hardware limits.

(2) Class AA is the more general cleanliness requirements; it is applicable to shop fabricated or purchased equipment where fixed surfaces contact liquid or gaseous pure oxygen.

(3) Class A is the least strigent class of cleanliness requirements; it is applicable to surfaces which through use will contact fluids other than pure oxygen, for example, liquid air or crude oxygen.

Cleanliness Requirements for Fiber Contaminants

The cleanliness requirements for fiber contaminants are not as extensive as for the particulate matter. The information listed in table I clearly indicates that stated requirements vary from disallowing presence of any fiber contaminants at all (White Sands Test Facility, sec. 49) (ref. 6) to the very explicit requirements exemplified by Plum Brook (Lewis Research Center, LeRC) RDL-003 (ref. 3). In this realm of variations the following are noteworthy:

(1) Nine sets of cleanliness requirements do not state allowable fiber contaminant limits.

(2) Eight sets of cleanliness requirements state one point limits above which fiber contaminants cannot be tolerated, namely, no fibers greater than 2000, 4000, or 6000 microns in length.

(3) The KSC (proposed, ref. 11) cleanliness requirements permit the fiber contaminants to be classed and counted as particulate matter contaminant.

(4) The GDA 0-75192B (ref. 19) cleanliness requirements, consistent with particulate matter contaminant treatment, explicitly differentiate between metallic and nonmetallic fiber allowable limits. These limits are also adjusted on the basis of verification techniques used. Metallic fiber contaminants are totally disallowed, while nonmetallic fiber contaminant limits vary from none greater than 2000 microns in length

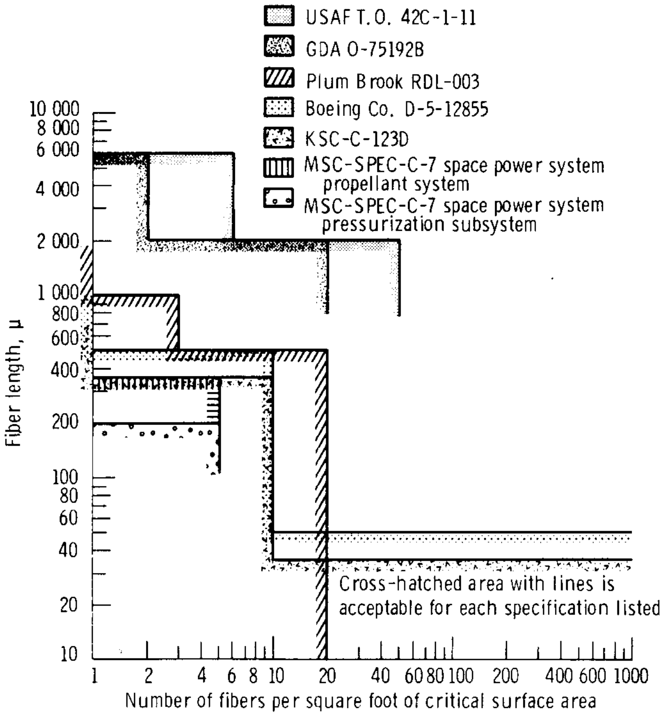

Figure 7. - Fiber-cleanliness requirements.

to none greater than 6000 microns in length depending on the systems involved.

The more explicit fiber contaminant requirements are illustrated in figure 7. The allowable fiber length limits are plotted as functions of the allowable population per square foot of critical surface area. Maximum allowable limits are indicated by the solid lines. Plum Brook (LeRC) cleanliness requirement limits for fiber type contaminants are the most explicit (ref. 3). These requirements limit fiber contaminant to 20 fibers of 0 to 500 microns in length, three fibers of 501 to 1000 microns in length, and one fiber to 1001 to 1875 microns in length. Thus, these specifications leave no doubt about the cleanliness level to be attained. Other requirements illustrated in the figure are less explicit.

Cleanliness Requirements for Condensable Hydrocarbons

Most of the cleanliness requirements do not indicate the condensable hydrocarbon type contaminant limits. In the few instances where the allowable contaminant limits are specified they vary from very explicit to extremely vague requirements. For example, from the data presented in table I the statements are as follows:

(1) Very explicit.

(a) 2.0 ppm by weight of test gas[1] (KSC-C-123D, ref. 10).

(b) 1.0 ppm by weight of test gas[1] (KSC proposed, ref. 11).

(c) 0 ppm by weight of test gas[1] (Plum Brook RDL-003, ref. 3).

(2) Explicit - no fluorescence on the cleaned surface using ultraviolet light (USAF T.O. 42C-1-11, (ref. 12); GDA 0-75192B (ref. 19); QCL 107F Air Products (ref. 4)).

(3) Vague.

(a) Low intensity fluorescence on the cleaned surface is acceptable (QCL 105F Air Products, ref. 4).

(b) No fluorescence (QCL 106F Air Products, ref. 4). (However, the specification allows isolated particles of lint on the cleaned surfaces.)

Cleanliness Requirements for the Remaining Types of Contaminants

Cleanliness requirements for solvent soluble organic residue, total solids, and other contaminants are either totally not stated or specified in the 1 to 5 milligram per square foot range of critical surface area. An exception is the Linde cleanliness requirement (ref. 8). It specifically limits nonvolatile residue to 500 milligrams per

[1]A sample of purge gas used to dry the system as part of the cleaning procedure.

square foot of critical surface area and solvent soluble organic residue to 10 milligrams per square foot of critical surface area. (The techniques used for measuring are discussed in the VERIFICATION OF CLEANLINESS section.)

For all the previously described contaminant limits the relation between the realistic cleanliness level and the specified cleanliness level is not defined in any of the requirements reviewed. There is no record in the documents reviewed of the basis for the selection of the cleanliness requirements generated by the separate groups within government and industry.

CLEANING PROCEDURES

Twenty-three cleaning procedures have been reviewed (refs. 2 to 22 and 25) to compare their approach to cleaning problems and highlight similarities or differences. A complete set of summaries of the procedures is given in the appendix and a complete set of detailed procedures is included in the attached microfiche supplement. Several general comments can be made regarding these cleaning procedures:

(1) All cleaning procedures except USAF T.O. 42C-1-11 (ref. 12) are written as guidelines and not as explicit specifications.

(2) Cleaning procedures vary according to the cleanliness requirements, the system components being cleaning, and the system materials.

(3) Cleaning procedures may be classified as aerospace clean or commercial clean.

(4) Cleaning procedures are most involved and costly for aerospace clean and least involved and costly for commercial clean.

A precautionary remark regarding cleaning agents and equipment used in these procedures is appropriate at this point. The toxicity of the cleaning solvents and the bodily harm associated with ultrasonically activated equipment or solutions present personnel health hazards which require protective measures.

There are five distinct steps that may be repeated several times in a given cleaning procedure. These steps are listed in table II (p. 66) with the associated information regarding cleaning agents, mechanical methods used with each step, and the purpose of each step. The particular sequence or number of these steps in a given procedure is a direct function of the cleanliness requirements and intended application or prior cleaning history of the item being cleaned.

The chemicals, cleaning agents, and mechanical aides used from table II vary as functions of materials of the components or systems being cleaned. In some instances cleaning procedures are specified according to the material used in the construction of the component, whereas in other instances the procedures are specified according to the components. The latter approach is most often used where two or more dissimilar materials (such as a metal and a nonmetal) or two different metals are used in fabricating the component. Not all cleaning agents can be used with such combinations of materials. For example, a highly acidic or alkaline cleaning agent may be suitable for one metal but not for the other, whereas some organic solvents may cause nonmetallic materials to swell and possibly degrade the physical or chemical properties due to solvent absorption or leaching action. Table III (ref. 26, pp. 68 to 71) illustrates some of the effects the common cleaning agents have on system materials. When all parts of a system cannot tolerate the same cleaning agent, they are cleaned separately before assembly. Subsequent assembly under clean conditions (clean room, etc.) avoids the need for further cleaning with strong agents.

An example of the cleaning procedures specified according to material as given in the appendix is presented in tables IV and V. Table IV (pp. 72 and 73) presents procedures for components made from various steel alloys, while table V (pp. 74 and 75) presents procedures for aluminum and its alloys. The procedures range from highly complex (i. e., numerous repetitions of basic steps) to very simple. The difference in metals to be cleaned affects the choice of cleaning agents, their concentrations, and metal exposure times and temperature ranges at which exposure to cleaning chemicals is made. This is evident, for example, by an examination of step 10 in table IV and step 8 in table V. For the steel alloys (step 10, table IV), cleaning agent formulation contains a quantity of phosphoric acid (exposure times range from 15 to 20 min) at temperatures between 80° and 175° F. For the aluminum and its alloys (step 8, table V), the cleaning formulation is mildly alkaline and exposure times are 30 to 120 minutes at 80° to 95° F or as short as 1 to 3 minutes at 140° to 180° F. Comparing the aforementioned individual cleaning steps for the given material, one becomes aware of the variations in cleaning agent concentrations, temperatures, and exposure times from one procedure to another. On the basis of the documents available at this time, technical justification for these differences cannot be established.

The information presented in tables IV and V must mirror the cleanliness requirements previously established. Thus, the cleaning procedures fall into the same general classes as the cleanliness requirements. The following are some examples:

(1) Aerospace clean. This category of cleaning procedures must meet the most demanding cleanliness requirements to ensure system reliability and safety. Cleaning procedures in this category can be further grouped into four distinct groups:

(a) Manned space flight. Preparation for such flights involves the greatest number of cleaning steps and related inspections to meet the most stringent cleanliness requirements for both space flight hardware and ground support equipment.

(b) Short duration space flight. For these flights the cleaning procedures are simplified somewhat by using fewer repetitive steps and inspections.

(c) Environmental chambers. These chambers could be environmental simulators on the ground or spacecraft cabins. A new factor, the human body, becomes an additional source of contamination. It is a living source of contamination which cannot be eliminated by cleaning. Therefore, the problems it presents must be accommodated by a very careful choice of materials, detailed design considerations, and corresponding operating procedures. The floors and walls, where feasible, are thoroughly scrubbed to remove visible soils (ref. 26). People are required to wear lintless protective clothing, booties, and head gear in the environmental chambers and the spacecraft prior to launch. This protective equipment is cleaned to oxygen service requirements.

(d) Research test apparatus. Relatively simple procedures are used if the apparatus is small and the consequences of fire or system failure are limited to tolerable levels.

(2) Commercial clean. This cleaning category generally involves the simplest cleaning procedures since the consequences of failure are designed to be small in ground-base commercial equipment built to large safety factors. Commercial oxygen processors do achieve aerospace clean conditions when required.

Cleaning is expensive. Cleaning requirements which are more exacting than the risk involved in system failure would justify are not cost effective.

VERFICATION OF CLEANLINESS

The verification methods for determining the cleanliness achieved are reviewed in references 2 to 22 and 25. A list of the more common verification tests are presented in table VI (pp. 76 to 78) along with a general description of the procedures used in each test, the results that should be expected, and the limitations of the test method. Verification of cleanliness usually involves a sequence of tests; these tests are presented separately in table VI. The types and sequence of verification methods to be used are usually specified along with the cleanliness requirements by the originating agency.

The tests described in the table are of two categories:

(1) Direct determination. The verification techniques are based on direct determination of the cleanliness condition of the critical surface:

(a) pH paper - to determine the acidity or alkalinity of the surface

(b) Wipe - to detect particulate matter

(c) Visual

(i) Ultraviolet light or black light - to detect hydrocarbons by means of fluorescence

(ii) Water break - to determine the presence of contaminant film by the water's inability to wet the surface

(iii) Flood light - to detect particulates

These are all qualitative in nature and are effective only in situations where the critical surface areas are easily accessible to sight or touch.

(2) Indirect determination. The verification techniques are based on the analysis of a sample of the final rinse fluid (gas or liquid) to indirectly determine the cleanliness condition of the critical surface. The test methods in this category are the following:

(a) Gas blowdown - to determine by filtering and counting the particulate contaminants collected on the filter paper

(b) Solvent flush - to determine by filtering and counting the particulate contaminants collected on the filter paper

(c) Solvent soluble organic residue - to detect and determine organic contaminants such as oils, hydrocarbons, protective film coatings, etc.

(d) Condensable hydrocarbons - to determine presence and quantity of hydrocarbons

(e) Nonvolatile residue - to determine the quantity of solid matter contaminants

Sampling and analysis of the final rinse fluid using the aforementioned tests constitute the entire basis for determining the cleanliness condition of the critical surface area. The fluid used in the final rinse operations has to be of exceptional purity to facilitate a reasonably accurate determination of the quantity of contaminants entrained by the fluid. Also, the sampling technique must be properly executed to obtain a highly representative sample of the rinse fluid. A properly executed sampling technique means the following:

(1) The quantity and number of samples taken must be commensurate with the sensitivity and precision of the cleanliness verification method used.

(2) The samples taken must be representative of the entire fluid used in flushing the critical surface area. Also, the sampling should be done at normal operating conditions of the system or component, and the sampling points must be properly located.

(3) The samples must be clear of extraneous contamination such as unclean sampling equipment.

Otherwise, the results achieved may be erroneous and an acceptably clean part may be rejected or unacceptably clean part may be accepted.

The gas blowdown and solvent flush tests are qualitative in nature, because the particle count is an estimate of an average count. The remaining three tests in this category are quantitative in nature because the infrared spectrophotometric or gravimetric determinations are used in establishing the quantity of the contaminants in the representative sample. The condensable hydrocarbon test, however, is probably the least accurate of the three. This is because of the intricate manipulations required to isolate the condensable hydrocarbons and because an arbitrary factor called "compensating evaporation factor" must be used in the computation to determine the concentration of the contaminants. These combine to severely degrade the test results.

In general, the reproducibility and accuracy of all the test results described in table VI vary widely and are functions of sampling procedures, the test methodology itself, and the ability and attitude of the technician performing the test.

A limited amount of verification methodology evaluation was performed by Hayes International under contract from Marshall Space Flight Center (ref. 27). This evaluation showed that evaporation of the solvent for nonvolatile residue content was erratic because of the effects of partial vapor pressures of the organic constituents, whereas infrared differential absorption spectroscopy yielded reproducible and accurate data. The evaluation also showed that the basic theoretical parameters required to provide for accurate and reproducible verifications have not been adequately defined.

The summary of a paper by J. P. McDonald of Martin Marietta Corporation (ref. 28) very aptly describes the current state-of-the-art:

> . . . It is not a well understood fact (outside of contamination control circles) that the sole quantitative content of all vehicle fluid system cleanliness criteria specifications for components lies in the content of the final rinse, the parameters for which have never been quantitatively defined. All effort expended on this activity in the vehicle aerospace field has relied on criteria that have not been dimensionally defined by determinative parameters, at least with regard to force of impingement, velocity (or "volume" of flow), orientation of surface being sampled, accessory sampling energy (e.g., insonation), or other characteristics that vitally affect the validity of results. The effort has depended almost totally on operator interpretation.

CONCLUDING REMARKS

The review of the cleanliness requirements, cleaning procedures, and verification techniques indicates the following:

1. Existing cleaning requirements generally allow the quantity of particulate contaminants to increase with a corresponding decrease in size of the particle whether metallic or nonmetallic.

2. Cleanliness requirements for manned space flight are the most stringent as regards allowable maximum particle size and quantity of particles, while general industrial requirements are the least demanding.

3. The quantitative justification for most of the requirements was not presented in the documents reviewed. Whether such justification exists or testing is required to es-

tablish the requirements cannot be stated from this review.

4. Large areas of uncertainty or areas subject to interpretation exist in some of the cleanliness requirements reviewed. For example, at a given particle size the permissible quantity is not specified in some cases.

5. The various cleaning procedures are all based on five steps: degrease, clean, rinse, inspect, and dry. The sequence and repetition of these steps in a given cleaning procedure depends on the stringency of the cleaning requirements.

6. The tests used to verify a required level of cleanliness are, in general, unsupported by adequate quantitative test data and are subject to the introduction of errors by the test technician.

7. Although very difficult to achieve, the proper balance between cleaning requirements, procedures, and verification techniques is quite necessary. Without it one may expend an unwarranted amount of time and effort unnecessarily recleaning an item or may damage the system by introducing an inadequately cleaned item.

8. Consideration should be given to establishing joint National Aeronautics and Space Administration - Department of Defense - American Medical Association - Environmental Protection Agency - industry effort to develop a series of uniform procedures. These should be based on actual test and experimental data and would establish the level of cleanliness required, methods of accomplishment, and verification as a function of the final application.

APPENDIX - CLEANING PROCEDURE SUMMARIES

Summaries of the cleaning procedures reviewed in this report (refs. 2 to 22 and 25) are contained in this appendix. These summaries are grouped according to the application of the cleaning procedures. The order of the grouping is as follows:

A. Components
   1. Breathing oxygen components - metallic
   2. Breathing oxygen components - nonmetallic
   3. Components with dissimilar elements
   4. Nonmetallic components containing nonmetallic parts
   5. Metal filter elements
   6. Transducers, pressure gages, dead-end cavity items

B. Materials
   1. Aluminum
   2. Brass, bronze, copper
   3. Carbon steel and carbon steel alloys

C. Tanks
   1. Aluminum and aluminum alloy tanks
   2. Cryogenic tanks

D. Tubing
   1. Aluminum alloy tubing
   2. Nonferrous pipe assemblies, tubing
   3. Steel pipe, pipe assemblies, tubing

A. Components

1. Breathing oxygen components - metallic
2. Breathing oxygen components - nonmetallic
3. Components with dissimilar elements
4. Nonmetallic parts and components containing nonmetallic parts
5. Metal filter elements
6. Transducers, pressure gages, dead-end cavity items

CLEANING METHODS AND PROCESSES, NASA FRC PROCESS SPECIFICATION 20-1, NOVEMBER 1, 1970 (REF. 22)

Specific Cleaning Processes for Breathing Oxygen Components - Metallic

Step	Process	Agent	Time, min	Temperature, °F	Remarks	Reference paragraph
1	Preclean				By hand wiping, brushing, and scraping.	6.3.1.1 (5.1.1)
2	Clean	Trichloroethylene	5		Ultrasonic or vapor degrease or flush with 5μ filtered solvent at circulation rate of 20 component volumes per minute. When flush procedure is used, heated solvent of 120° - 140° F is desired, but in no case shall temperature be less than 60° F.	6.3.1.1 (5.1.2)
3	Rinse	Trichloroethylene			Solvent shall be fresh filtered (5μ nominal). Step omitted if flush procedure used in step 2.	6.3.1.1 (5.1.3)
4	Dry	Dry nitrogen and/or heating to		180 (max)	Nitrogen filtered to 5μ nominal.	6.3.1.1 (5.1.4)
5	Flush	Ethyl alcohol			Filtered 5μ nominal.	6.3.1.2
6	Rinse	Demineralized or distilled water				6.3.1.3
7	Dry	Dry nitrogen or by heating to		180 (max)		6.3.1.4
8	Check	Halogen detector			Sniff check or equivalent to ensure that all traces of trichloroethylene or other halogen vapors are removed.	6.3.1.5

CLEANING METHODS AND PROCESSES, NASA FRC PROCESS SPECIFICATION 20-1, NOVEMBER 1, 1970 (REF. 22)

Basic Cleaning Process for Metallic Articles

Step	Process	Agent	Time, min	Temperature, $^{\circ}F$	Remarks	Reference paragraph
1	Preclean				By wiping, brushing, and scraping.	5.1.1
2	Clean	Trichloroethylene	5		Ultrasonic or vapor degrease or flush with 5μ filtered trichloroethylene at circulation rate of 20 component volumes per minute. When flush procedure is used heated trichloroethylene of 120° - 140° F is desired, but in no case shall temperature be less than 60° F.	5.1.2
3	Rinse	Trichloroethylene			Solvent shall be fresh, filtered (5μ nominal). Step omitted if flush procedure used in step 2.	5.1.3
4	Dry	Dry nitrogen and/or heat to		180 (max)	Nitrogen filtered to 5μ nominal.	

CLEANING METHODS AND PROCESSES, NASA FRC PROCESS SPECIFICATION 20-1, NOVEMBER 1, 1970 (REF. 22)

Specific Cleaning Processes for Breathing Oxygen Components - Nonmetallic

Step	Process	Agent	Time, min	Temperature, ^{o}F	Remarks	Reference paragraph
1	Preclean	Paper			Hand wipe clean of any visible grease, oil, or contaminants.	6.3.2 (5.2.1)
2	Clean	1% nonionic detergent and water solution		140 (max)	Either scrub with nonmetallic brush, flush with detergent solution at flow rate of 20 component volumes per minute for 3 minutes, or ultrasonic clean in detergent solution.	6.3.2 (5.2.2)
3	Dry	Dry, oil-free nitrogen gas or air				6.3.2 (5.2.3)
4	Rinse	Demineralized or distilled water		140 (max)		6.3.2 (5.2.4)
5	Dry	(a) Dry, oil-free nitrogen gas			Filtered through 5μ filter.	6.3.2 (5.2.5)
		(b) Heat in oven		120 - 140	Nonmetallic gaskets or parts, such as O-rings, shall not be subjected to temperature above 140^{o} F.	
		(c) Vacuum				
6	Check	Halogen detector			Sniff check of equivalent to ensure that all traces of trichloroethylene or other halogen vapors are removed.	6.3.2

CLEANING METHODS AND PROCESSES, NASA FRC PROCESS SPECIFICATION 20-1, NOVEMBER 1, 1970 (REF. 22)

Basic Cleaning Process for Nonmetallic Articles

Step	Process	Agent	Time, min	Temperature, °F	Remarks	Reference paragraph
1	Preclean	Paper			Hand wipe clean of any visible grease, oil, or contaminants.	5.2.1
2	Clean	1% nonionic detergent and water solution		140 (max)	Either scrub with nonmetallic brush, flush with detergent solution at flow rate of 20 component volumes per minute for 3 minutes, or ultrasonic clean in detergent solution.	5.2.2
3	Dry	Dry, oil-free nitrogen gas or air				5.2.3
4	Rinse	Demineralized or distilled water		140 (max)		5.2.4
5	Dry	(a) Dry, oil-free nitrogen gas (b) Heat in oven		 120 - 140	Filtered through 5μ filter. Nonmetallic gaskets or parts, such as O-rings, shall not be subjected to temperatures above 140° F.	5.2.5

KSC (PROPOSED)
NONMETALLIC MATERIALS (REF. 11)

[Ref. par. 3.10.2.1.2 and others as noted. Removable nonmetallic parts may be cleaned as separate items. When nonmetallic parts cannot be removed it shall be cause to clean the item as a nonmetallic.]

Step	Process	Agent	Time, min	Temperature, ^oF	Remarks	Reference paragraph
1	Clean	0.5% solution of detergent per MIL; D-16791 and deionized water	5 - 15	110 - 130	Clean by flushing, soaking, spraying, or sonic energy.	3.9.3.3
2	Rinse	Water	5	90 - 110		
3	Rinse	Deionized water	5		If ultrasonic cleaning used, rinse for additional 10 minutes in ultrasonic cleaner.	
4	Inspect	Narrow range pH paper			pH must be between 6 and 8, otherwise repeat steps 1 - 3.	4.3
5	Dry	Gaseous nitrogen or vacuum drying oven		100 - 120	Type I, class 1, grade B of spec. BB-N-411.	3.10.2.4
6	Clean	Trichlorotrifluoroethane or isopropyl alcohol	1		Use only compatible solvent-material combinations.	
7	Inspect				Particle count of fluid from step 6, in accordance with 4.3.	
8	Dry	Gaseous nitrogen or vacuum oven		100 - 120	Remove all traces of solvent (see spec. BB-N-411).	

SYSTEMS AND EQUIPMENT CLEANING, CPIA PUBLICATION 194
ROCKET PROPELLANTS(B) OXYGEN (REF. 21)

Plastic Parts

Step	Process	Agent	Time, min	Temperature, $^{\circ}F$	Remarks	Reference paragraph
1	Disassemble				To separate aluminum steel and plastic parts.	10. a. 1
2	Clean	4% detergent solution	30	120		10. b. 1
3	Rinse	Distilled water			Several times.	10. b. 2
4	Dry	Nitrogen gas				10. b. 3

CLEANING AND INSPECTION PROCEDURES FOR BALLISTIC MISSILE SYSTEMS T.O. 42C-1-11 CHANGE 2, NOVEMBER 15, 1967 (REF. 12)

Electroplated Parts and Components Containing Dissimilar Metals

Step	Process	Agent	Time, min	Temperature, °F	Remarks	Reference paragraph
1	Degrease	Trichloroethylene or trichlorotrifluoroethane	As required	Ambient		3-15 3-75
2	Vapor degrease	Trichloroethylene or trichlorotrifluoroethane		Boiling	Immerse parts in vapor until condensation ceases. Flush with freshly condensed degreaser solvent.	3-15 3-64
3	Alkaline clean	Alkaline cleaner: 5 - 10 oz/gal tap water	15 - 25	150 - 175	Parts shall be completely free of step 2 solution because of explosion hazard.	3-77
4	Rinse	Tap water	5 - 10	150		3-84
5	Rinse	Demineralized water	5 - 10	150		3-84
6	Dry	Oven, nitrogen gas, or vacuum		180 - 200 140		3-87
7	Rinse	Detergent solution: 1/2 - 1 oz/gal tap water, demineralized water, or trichloroethylene	15 - 25 As required	120 - 140	MIL-D-16791 type I.	3-86 3-85
8	Flush	Demineralized water	As required	150	Do not flush of solvent used in step 7.	
9	Inspect					
10	Dry	Oven, nitrogen gas, or vacuum		180 - 200 140		3-87

CLEANING AND INSPECTION PROCEDURES FOR BALLISTIC MISSILE SYSTEMS T.O. 42C-1-11 CHANGE 2, NOVEMBER 15, 1967 (REF. 12)

Nonmetallic Parts and Components Containing Nonmetallic Parts

Step	Process	Agent	Time, min	Temperature, ^{o}F	Remarks	Reference paragraph
1	Detergent clean	Detergent solution: 1/2 - 1 oz/gal of tap or demineralized water	5 - 10	120 - 140	MIL-D-16791 type I.	3-86
2	Rinse	Tap water	5 - 10	150		3-84
3	Rinse	Demineralized water	5 - 10	150		3-84
4	Dry	Oven, nitrogen gas, or vacuum		180 - 200 140		3-87
5	Detergent rinse	Detergent solution: 1/2 - 1 oz/gal of tap or demineralized water	15 - 20	120 - 140		3-86
6	Inspect					3-89
7	Dry	Oven, nitrogen gas, or vacuum		180 - 200 140		3-86

CLEANING AND INSPECTION PROCEDURES FOR BALLISTIC MISSILE SYSTEMS T.O. 42C-1-11 CHANGE 2, NOVEMBER 15, 1967 (REF. 12)

Metal Filter Elements

Step	Process	Agent	Time, min	Temperature, ^{o}F	Remarks	Reference paragraph
1	Vapor degrease	Trichloroethylene or trichlorotrifluoroethane	As required	Boiling	MIL-T-27602 (FSN 6850-681-5688).	3-64
2	Dry	Oven, nitrogen gas, or vacuum		180 - 200 140		3-87
3	Ultrasonic clean	Trichloroethylene or trichlorotrifluoroethane	3 - 5	10^{o} below boiling point		3-15 3-79
4	Rinse	Trichloroethylene	5 - 7	Ambient	Solvent filtered through 10μ filter.	3-85
5	Inspect					
6	Dry	Oven, nitrogen gas, or vacuum		180 - 200 140		3-87

CLEANING, TESTING, AND HANDLING OF OXYGEN, FUEL, AND PNEUMATIC COMPONENTS
D5-12855, BOEING CO., MAY 15, 1968 (REF. 9)

Dead-End Components (Pressure Gages, Transducers, etc.)

[Ref. par. 3.0 and others as noted. Components not to be immersed in cleaning media, and, also, components not to be exposed to acid (ref. par. 3.1).]

Step	Process	Agent	Time, min	Temperature, ^{o}F	Remarks	Reference paragraph
1	Inspection	Prior to precleaning			Inspect exterior and visible interior.	5.2
2	Precleaning	Trichloroethylene precision cleaning agent, Dowclene WR			Alternating vacuum solvent flush (28 in. of Hg min. vacuum). Fill and drain component a minimum of 20 times. Fresh solvent for each fill. Two other methods are also stated.	6.2.2
3	Final cleaning	Trichloroethylene precision cleaning agent, Dowclene WR, use minimum quantity of solvent per 7.3.1			Rinse significant surfaces using one of the methods in 3.2. Must be in controlled environment per 6.3.2.	3.3
4	Drying	Nitrogen gas per BB-N-411; air or other gas to be specifically approved by engineering		130 - 250	Temperature dependent on parts (see 6.2.6). Vacuum oven drying is preferred.	3.3 6.2.7

CLEANING AND INSPECTION PROCEDURES FOR BALLISTIC MISSILE SYSTEMS T.O. 42C-1-11 CHANGE 2, NOVEMBER 15, 1967 (REF. 12)

Transducers, Pressure Gages, and Other Dead-End Cavity Parts

Step	Process	Agent	Time, min	Temperature, °F	Remarks	Reference paragraph
1	Fill	Trichloroethylene			3/4 full and rotate component gently to circulate fluid. Repeat fill and rotate procedure two times.	3-15
2	Rinse	Petroleum ether				
3	Inspect					3-89
4	Dry	Oven, nitrogen gas, or vacuum		180 - 200 140		3-87

CLEANING OF OXYGEN PRESSURE GAGE COMPONENTS, NAVAL BOILER, AND TURBINE LABORATORY, MARCH 26, 1965 (REF. 18)

Step	Process	Agent	Time, min	Temperature, °F	Remarks	Reference paragraph
1	Disassemble				Disconnect from piping system, remove back of gage, elongate coil of capillary tubing, and open capillary tubing filing off tip.	1-6
2	Clean	Freon PCA			Forced by air pressure (5 psig) flow 150 ml of Freon PCA at approximately 50 ml/min. Repeat with two additional 124 ml portions and reverse flush with 100 ml of solvent.	7-10
3	Rinse	Freon PCA			Introduce 50 ml of solvent through connection end of gage, collect effluent in white porcelain dish, and evaporate to dryness.	11
4	Inspect	Ultraviolet light (3600 - 3900 Å)			White dish from step 3 checked for fluorescence. If fluorescence observed, continue flushing.	11-12
5	Assemble					13-15

CLEANING AND TESTING OF OXYGEN AND NITROGEN GAS PIPING SYSTEMS
MIL-STD-1330 (SHIPS), MAY 10, 1968 (REF. 20)

Bourdon C Tube Pressure Gages

Step	Process	Agent	Time, min	Temperature, ^{o}F	Remarks	Reference paragraph
1	Disassemble					4. 5. 1. 1
2	Clean	Trichlorotrifluoroethane			MIL-C-81302 type I ultra-clean at flow rate of 50 mil/min.	4. 5. 1. 8
3	Check	Ultraviolet light (3600 - 3900 Å)			Continue flushing if fluorescence is evident.	4. 5. 1. 10
4	Dry	Dry, oil-free nitrogen				4. 5. 1. 11

CLEANING METHODS AND PROCESSES, NASA FRC PROCESS
SPECIFICATION 20-1, NOVEMBER 1, 1970 (REF. 22)

Specific Cleaning Process for Pressure Transducers and Bourdon Tubes

Step	Process	Agent	Time, min	Temperature, ^{o}F	Remarks	Reference paragraph
1	Preclean	Trichloroethylene			Hot solvent.	6. 5. 1. 1
2	Clean	Trichloroethylene	1	180±5	Soak in hot solvent.	6. 5. 1. 2
			1	Ambient	Place in ambient solvent. Repeat cycle 10 times. Ambient solvent not to exceed 85^{o} F.	6. 5. 1. 3
3	Dry	Oven	150	250±10	For Bourdon tubes.	6. 5. 1. 4
			150	180±10	For pressure transducers.	

B. Material
   1. Aluminum
   2. Brass, bronze, copper
   3. Carbon steel and carbon steel alloys

CLEANING AND INSPECTION PROCEDURES FOR BALLISTIC MISSILE SYSTEMS T. O. 42C-1-11 CHANGE 2, NOVEMBER 15, 1967 (REF. 12)

Aluminum

Step	Process	Agent	Time, min	Temperature, ^{o}F	Remarks	Reference paragraph
1	Mechanical descaling		As required			3-39
2	Degrease	Trichloroethylene	As required	Ambient	MIL-T-27602.	3-15 3-75
3	Vapor degrease	Trichloroethylene or trichlorotrifluoroethane			MIL-T-27602 (FSN 6850-681-5688).	
4	Alkaline clean	Sodium carbonate (3 oz/gal), trisodium phosphate (3 oz/gal), remainder tap water	1 - 3	140 - 180		
5	Rinse	Tap water		150		
6	Pickle	HNO_3 (12% by volume), HF (1% by volume), remainder tap water		Ambient		
7	Rinse	Demineralized water		150		
8	Dry	Oven heated nitrogen or vacuum		180 - 200 140	MIL-P-27401; filtered through 10μ filter.	
9	Rinse	Detergent solution: 1/2 - 1 oz of sol/gal tap or demineralized water or trichloroethylene	15 - 25	120 - 140	MIL-D-16791 type I. MIL-T-27602.	
10	Flush	Demineralized water	As required	150	Do not flush if solvent used in step 9.	
11	Inspect					
12	Dry	See step 8				

CLEANING PROCEDURES - METALS CLEANING SPI-49. 111
LINDE COMPANY, DIV. OF UNION CARBIDE, DECEMBER 28, 1965 (REF. 8)

Aluminum

Step	Process	Agent	Time, min	Temperature, °F	Remarks	Reference paragraph
1	Preclean	Diversey 1319 (1) 3 oz/gal		Ambient	(1) Code 3008-2825: step 1, preclean with solution gun only if aluminum is contaminated with oil or other heavy soil.	.02. 1
2	Rinse	Cold water (2) or hot water (2)			(2) Water shall be potable. (3) Code 3008-3000.	.02. 2
3	Clean/etch	Aluminux: Diversey aluminum (6 oz/gal) Diversey 202(4) (2 oz/gal of water)	(5) 1 - 2	160	(4) Code 3008-2775. (5) For light gage material; heavy gage material not to be soaked longer than necessary.	.02. 3
4	Rinse	Hot water				.02. 4
5	Deoxidize or desmut	Diversey 596(6) (7 oz/gal water), H_2SO_4 (7% by volume), remainder water			(6) Code 3002-1300.	.02. 5
6	Rinse	Hot water				.02. 6
7	Dry	Air (7)			(7) Clean, dry, oil free.	

SYSTEMS AND EQUIPMENT CLEANING, CPIA PUBLICATION 194
ROCKET PROPELLANTS(B) OXYGEN (REF. 21)

Aluminum, Aluminum Alloys

Step	Process	Agent	Time, min	Temperature, °F	Remarks	Reference paragraph
1	Disassembly				To separate aluminum plastic and steel parts.	10. a. 1
2	Degrease	Perchloroethylene	30			10. a. 2
3	Rinse	Alcohol				10. a. 2
4	Rinse	Water				10. a. 2
5	Clean	4% solution of aluminum cleaner	30			10. a. 3
6	Rinse	Water				10. a. 3
7	Final clean	Steam				10. a. 5a
8	Dry	Nitrogen				10. a. 5b

ALUMINUM CLEANED BY SOLUTION SPRAYING
KSC (PROPOSED) (REF. 11)

[Ref. Par. 3.10.3.5 and others as noted.]

Step	Process	Agent	Time, min	Temperature, °F	Remarks	Reference paragraph
1	Precleaning	Trichloroethylene type II, trichlorotrifluoroethane, or 0.5% solution of a detergent in deionized water	5 - *15	110 - *130	Conform to MSFC-SPEC-217. Conform to MSFC-SPEC-237. *For detergent solution only.	3.10.3.5.1a (3.9.3 & 3.10.3.1)
2	Clean	Formula IV: % by wt — Material 9±0.4 — 2-butoxy-ethanol solvent 1.5±0.1 — Na_2HPO_4 0.5±0.05 — Surfactant (alkyl aryl polyethylene glycol ether) Remainder deionized water	60 - 120	80 - 95	Spray minimum flow of 6 gal/min/ft at item; maximum i.d. at a spray head delivery; P = 150 - 200 psig.	3.10.3.5.1b (3.10.3.3.3)
3	Rinse	Deionized water	30	Ambient	Delivery rate same as step 2. Continue rinse until evidence of surfactant disappears.	
4	Brighten	Formula V: % by vol — Material 23±0.5 — 61% HNO_3 Remainder deionized water	20 - 40	Ambient	Spray delivery rate same as step 2.	3.10.3.5.1c (3.10.3.3)
5	Rinse	Steps 1 and 3			Steps 4 and 5 to be accomplished if smut has developed on the part during steps 1 - 3.	3.10.5.1d

Continued. ALUMINUM CLEANED BY SOLUTION SPRAYING
KSC (PROPOSED) (REF. 11)

Step	Process	Agent	Time, min	Temperature, ^{o}F	Remarks	Reference paragraph
6	Final rinse	Deionized water			(1) For rotating head spray machine - (a) Lower spray head to lowest point of item cleaned. (b) Spray at rate 2.2 gal/min/ft. (c) Delivery P = 150 - 200 psig. (d) Rinse spray head vertically at rate of 1 ft/min. (e) Take test samples from lowest point. (f) 2500 ml sample to be obtained in 58 - 62 sec. (g) Steps (a) - (e) must be correlated so that 2500 ml test sample will represent 1 ft^2 of critical surface area. (h) Collect first 2500 mil sample at start of spray; second when spray head traversed 50% of vertical distance; collect third sample as spray head approaches highest point. (2) For rotating spray wand - same as step 6 except 2500 ml samples will be taken at first, third, and fifth minutes of spray.	3.10.3.5.1d

Concluded. ALUMINUM CLEANED BY SOLUTION SPRAYING
KSC (PROPOSED) (REF. 11)

Step	Process	Agent	Time, min	Temperature, °F	Remarks	Reference paragraph
7	pH test	Narrow range pH paper			All samples analyzed to to 4.3. pH sensitive to 0.1 pH unit. pH range, 6.0 - 8.0. If nonconformance flush 15 minutes and test, on second failure reclean steps 1 - 6.	3.10.3.5.1e (3.10.3.3i)
8	Dry	Gaseous nitrogen			To a dew point of -65° F at all critical parts per 4.3. Final 5 minutes gaseous nitrogen at system operating pressure; if unattainable, purge velocity at farthest downstream exit port, shall be 35 SCFM.	(3.10.3.3j) (3.10.3.3k)
9	Repeat rinse	Trichloroethylene; trichlorotrifluoroethane	15		Flow rate of 6 gal/min/ft. Spray head pressure 80 - 100 psig.	
10	Drain					
11	Repeat rinse	Step 6 (1) or 6 (2)			Delivery pressure, 20 - 100 psig. Test solvent - if unacceptable, repeat steps 1 - 11.	
12	Test					
13	Dry	Same as step 8				

KSC (PROPOSED) (REF. 11)

Aluminum

[Ref. par. 3. 10. 2. 3 and others as noted.]

Step	Process	Agent	Time, min	Temperature, ^{o}F	Remarks	Reference paragraph
1	Mechanical descale	Brushing, shot peening, etc.			As required.	3. 9. 2
2	Degrease	Trichloroethylene or trichlorotrifluoroethane			Solvent or vapor MSFC-SPEC-217 or MSFC-SPEC-237.	3. 9. 3. 1
3	Dry	Gaseous nitrogen			Type I, class 1, grade B of spec. BB-N-411.	3. 10. 2. 4
4	Remove corrosion	23±5% by volume of 61% nitric acid, remainder is deionized water	10 - 60	Ambient	Formula V.	3. 10
5	Rinse	Water	5	90 - 110		
6	Rinse	Deionized water	3			
7	Dry	Gaseous nitrogen		120 - 140		
[a]8	Clean	By weight:				
		9% 2-Butoxyethanol solvent 1. 5% Sodium phosphate, dibasic, anhydrous 0. 5% Surfactant Remainder is deionized water	30 - 120	80 - 95	Flush, soak, brush, or sonic clean.	3. 10
9	Rinse	Water	5	90 - 110		
10	Rinse	Deionized water	3		If ultrasonic cleaning used, rinse additional 10 minutes in ultrasonic cleaner.	
11	Brighten and passivate	Same as step 4	10 - 30	Ambient	Step 8, cleaning is usually adequate.	
12	Rinse	Water	5	90 - 110	Only if step 11 used.	

[a]All fluids used in steps 8 to 18 shall be prefiltered prior to use to meet the cleanliness level specified for the item when tested according to 4. 5. 2.

Concluded. KSC (PROPOSED) (REF. 11)

Step	Process	Agent	Time, min	Tempera- ture, °F	Remarks	Reference paragraph
13	Rinse	Deionized water	5		Only if step 11 used.	
14	pH test	Narrow range pH paper			Repeat steps 2 - 13 if pH not between 6. 0 and 8. 0.	
15	Dry	Gaseous nitrogen		120 - 140	Vacuum drying oven also acceptable.	
16	Flush	Trichlorotrifluoroethane	1		MSFC-SPEC-237.	
17	Inspect				By analysis of fluid from 16.	
18	Dry	Gaseous nitrogen		120 - 140	Vacuum drying oven also acceptable.	

CLEANING, TESTING, AND HANDLING OF OXYGEN, FUEL, AND PNEUMATIC COMPONENTS
DS-12855, BOEING CO., MAY 15, 1968 (REF. 9)

Coated Aluminum

[Not to be subjected to temperatures exceeding 130° F.]

Step	Process	Agent	Time, min	Temperature, °F	Remarks	Reference paragraph
1	Rough cleaning				Clean per BAC5765.	7. 5. 2a
2	Solvent flush	Trichloroethylene, precision cleaning agent, or Dowclene WR				6. 2. 2
3	Ultrasonic detergent	Detergent-water solution (1)	5	130 (max) (2)	(1) Water distilled or deionized having minimum specific resistance of 50 000 Ω. Detergents conform to MIL-D-16791 type I. Detergent concentration, 0. 1 - 0. 6 oz/gal of water. (2) Solution may be heated to 130° F (max), provided it is followed by a heated (max, 130° F) water rinse.	6. 2. 4
4	Ultrasonic water rinse	Distilled or deionized water (3)	5		(3) Must have minimum specific resistance of 50 000 Ω and pH 6. 0 - 8. 0.	6. 2. 5
5	Dry	Nitrogen gas, air, or other gas specifically approved by engineering			(4) Gas shall meet requirements of 6. 2. 1. 1: shall not contain considerable hydrocarbons in excess of 3 ppm by weight, shall not exceed 60% relative humidity at ambient temperature. (5) Drying gas may be heated providing parts do not exceed 130° F for MIL-C-5541 coated parts.	6. 2. 6 or 6. 2. 7

Concluded. CLEANING, TESTING, AND HANDLING OF OXYGEN, FUEL, PNEUMATIC COMPONENTS DS-12855, BOEING CO., MAY 15, 1968 (REF. 9)

Step	Process	Agent	Time, min	Temperature, °F	Remarks	Reference paragraph
6	Visual acceptance inspection					4.9
7	Final flush	Step 2	3			6.2.2
8	Dry	Step 5				6.2.6 or 6.2.7

CLEANING AND INSPECTION PROCEDURES FOR BALLISTIC MISSILE SYSTEMS T. O. 42C-1-11 CHANGE 2, NOVEMBER 15, 1967 (REF. 12)

Brass, Copper, and Bronze

Step	Process	Agent	Time, min	Temperature, °F	Remarks	Reference paragraph
1	Mechanical descaling		As required			3-39
2	Degrease	Trichloroethylene	As required	Ambient	MIL-T-27602.	3-15 3-75
3	Vapor degrease	Trichloroethylene or trichlorotrifluoroethane			MIL-T-27602 (FSN 6850-681-5688).	3-15 3-16 3-64
4	Alkaline clean	Alkaline cleaner: 5 - 10 oz/gal tap water		150 - 175	Fed. spec. P-C-436.	3-59
5	Rinse	Tap water	5 - 10	150		
6	Pickle	H_2SO_4, 8.6% by volume; HNO_3, 1.4% by volume; demineralized water, 90% by volume; or HF, 10 - 15% by volume; demineralized water for remainder		120 - 130	Solution temperature and immersion time to be determined from test coupons.	3.61
7	Rinse	Demineralized water	5 - 10	150		
8	Dry	Oven, nitrogen gas, or vacuum		180 - 200 140		3-87
9	Rinse	Detergent solution: 1/2 - 1 oz/gal of tap water, demineralized water, or trichloroethylene	15 - 25	120 - 140	MIL-D-16791 type I.	3-86 3-85
10	Flush	Demineralized water	As required	150	Do not flush if solvent used in step 9.	
11	Inspect					3-89
12	Dry	Same as step 8				3-87

KSC (PROPOSED) (REF. 11)

Copper and Copper Alloys (3. 10. 2. 4)

Step	Process	Agent	Time, min	Temperature, ^oF	Remarks	Reference paragraph
1	Mechanical descale	Brushing, shot peening, etc.			As required.	3. 9. 2
2	Degrease	Trichloroethylene or trichlorotrifluoroethane			MSFC-SPEC-217. MSFC-SPEC-237.	3. 9. 3. 1
3	Dry	Gaseous nitrogen			Type I, class 1, grade B of spec. BB-N-411.	3. 10. 2. 4
4	Corrosion removal	6. 5 - 93% Sulfuric acid 17 - 61% Nitric acid Remainder is deionized water	10 - 30	Ambient	For heavy corrosion.	3. 10. 1. 7
5	Rinse	Water	5	90 - 110	One if step 4 is used.	
6	Rinse	Deionized water	3			
7	Dry	Gaseous nitrogen		120 - 140		
8	Clean	30 - 85% Orthophosphoric acid 20 - 2% 2-Butoxyethanol solvent 1% Surfactant Remainder is deionized water	60 - 90	80 - 105	Will remove light corrosion and oxidation so that step 4 may not be required.	3. 10. 2. 4
9	Rinse	Water	5	90 - 110		
10	Rinse	Deionized water	3		If ultrasonic cleaner used, rinse additional 10 minutes in ultrasonic cleaner.	3. 10. 2. 4
11	Brighten	Same as 4	10 - 30	Ambient	For cupro-nickel alloys and silicon bronzes	3. 10. 2. 4
12	Rinse	Water	5	90 - 110	Only if step 11 is used.	3. 10. 2. 4
13	Rinse	Deionized water	5			
14	pH test	pH paper (narrow range)			Repeat steps 2 - 13 if pH not between 6. 0 and 8. 0.	3. 10. 2. 4

Concluded. KSC (PROPOSED) (REF. 11)

Step	Process	Agent	Time, min	Tempera-ture, ^{o}F	Remarks	Reference paragraph
15	Dry	Gaseous nitrogen or vacuum drying oven		120 - 140		3. 5. 7. 2
16	Flush	Trichlorofluoroethane	1		MSFC-SPEC-237.	3. 10. 2. 4
17	Inspect				By analysis of fluid from 16 in accordance with 4. 3.	
18	Dry	Gaseous nitrogen (same as step 15)				

CLEANING AND INSPECTION PROCEDURES FOR BALLISTIC MISSILE SYSTEMS T.O. 42C-1-11 CHANGE 2, NOVEMBER 15, 1967 (REF. 12)

Carbon Steel and Carbon Steel Alloys

Step	Process	Agent	Time, min	Temperature, °F	Remarks	Reference paragraph
1	Mechanical degrease		As required			3-39
2	Degrease	Trichloroethylene			MIL-T-27602.	3-15 3-75
3	Vapor degrease	Trichloroethylene or trichlorotrifluoroethane	As required	Degreaser operating temperature	MIL-T-27602 (FSN 6850-681-5688).	3-15
4	Alkaline clean	Alkaline cleaner 5 - 10 oz/gal of tap or demineralized water	15 - 20	150	Fed. spec. P-C-436. Parts shall be completely free of step 3 solvents because of possible explosion hazard.	3-77
5	Rinse	Tap water	5 - 10	150		3-84
6	Pickle	HF, 15 - 20% by volume; Rodine 50 or equivalent inhibitor, 0.25 - 0.50% by volume; tap water, balance.	15 - 30	Ambient		3-51
7	Rinse	Tap water	5 - 7	150	Omit if step 6 omitted.	3-84
8	Rinse	Demineralized water	3 - 5	150		3-84
9	Bake		180	375±25	Required only for steels harder than Rockwell C32 to prevent hydrogen embrittlement.	
10	Protective coat	Corrosion preventative	As required	Ambient		3-55
11	Dry	Oven, nitrogen gas, or vacuum	As required	180 - 200 140		3-87
12	Rinse	Detergent solution, 1/2 - 1 oz/gal tap water, demineralized water, or trichloroethylene	15 - 25	120 - 140	MIL-D-16791 type I.	3-86

Concluded. CLEANING AND INSPECTION PROCEDURES FOR BALLISTIC MISSILE SYSTEMS T. O. 42C-1-11 CHANGE 2, NOVEMBER 15, 1967 (REF. 12)

Step	Process	Agent	Time, min	Temperature, °F	Remarks	Reference paragraph
13	Flush	Demineralized water	As required	150	Do not flush if solvent used in step 12.	
14	Inspect					
15	Dry	Same as step 10.				3-87

PLUM BROOK RDL-003 (REF. 3)

Carbon/Steel

Step	Process	Agent	Time, min	Temperature, °F	Remarks	Reference paragraph
1	Degrease	Trichloroethylene (Fed. spec. O-T-634b) or detergent-water solution		140 - 160	As required. As required.	3. 1. 1
2	Rinse	Distilled or deionized water			Until detergent is no longer evident.	3. 1. 2
3	Clean	20% by volume of inhibited hydrochloric acid (Fed. spec. O-A-86)			Until area is clean and free of rust and scale.	3. 1. 3
4	Rinse	0. 02% by weight of citric acid solution			Continue rinse until effluent pH = influent pH.	3. 1. 4
5	Flush	By weight a solution of 0. 5% sodium hydrooxide, 0. 5% sodium nitrate, 0. 25% monosodium phosphate with distilled or deionized water.	30			3. 1. 5
6	Inspect					4. 0
7	Dry	Dry, hydrocarbon-free, gaseous nitrogen	2		As required.	3. 1. 6
8	Package					

C. Tanks

1. Aluminum and aluminum alloy tanks
2. Cryogenic tanks

SYSTEMS AND EQUIPMENT CLEANING, CPIA PUBLICATION 194
ROCKET PROPELLANTS(B) OXYGEN (REF. 21)

Aluminum and Aluminum Alloy Tanks

Step	Process	Agent	Time, min	Temperature, °F	Remarks	Reference paragraph
1	Preclean				Remove burns, grease, dirt, scale.	10. d. 1
2	Degrease	Solvent	30			10. d. 2
3	Rinse	Alcohol				10. d. 3
4	Wash	Water				10. d. 4
5	Clean	4% aluminum cleaning solution	20	Room		10. d. 5
6	Wash	Water or steam clean				10. d. 7
7	Dry	Dry nitrogen				10. d. 7

CLEANING PROCEDURES - METALS CLEANING SPI-49. 111
LINDE COMPANY, DIV. OF UNION CARBIDE, DECEMBER 28, 1965 (REF. 8)

Aluminum Shells

Step	Process	Agent	Time, min	Temperature, °F	Remarks	Reference paragraph
1	Etch	Diversey aluminux, (1) 6 oz/1 gal water; Diversey 202 (2) 2 oz/gal water		160	Swab with solution: (1) Code 3008-3000 (2) Code 3008-2775	. 08. 1
2	Rinse	Cold water (3)			(3) Water shall be potable.	. 08. 2
3	Deoxidize/ desmut	Diversey 596, 7 oz/gal water; H_2SO_4 7% by volume; remainder water		Ambient	Swab with solution inside and outside of the shell.	. 08. 3
4	Rinse	Cold water				. 08. 4

CLEANING OF CRYOGENIC TANKS FOR LO_2, LN_2, AND LH_2 SERVICE, AIR FORCE ROCKET PROPULSION LABORATORY TECHNICAL INSTRUCTION, AFRPL TI 5-4-3, NOVEMBER 1967 (REF. 25)

Step	Process	Agent	Time, min	Temperature, °F	Remarks	Reference paragraph
1	Clean	Solvent			Hot vapors of unspecified solvent until inlet and outlet temperatures are within 5° F.	6. c. 1
2	Dry	Nitrogen gas			Purge with warm gas filtered through 10 μ filter until escaping gas smells sweet (no evidence of characteristic solvent fumes) and registers a dew point of -63° F or less.	6. c. 2

CLEANING OF CRYOGENIC TANKS FOR LO_2, LN_2, and LH_2 SERVICE, AIR FORCE ROCKET PROPULSION LABORATORY TECHNICAL INSTRUCTION, AFRPL TI 5-4-3, NOVEMBER 1967 (REF. 25)

Detergent or Alkaline Solution Cleaning

Step	Process	Agent	Time, min	Temperature, °F	Remarks	Reference paragraph
1	Preclean	Vacuum			NO SWEEPING, dust cannot be removed from the vessel.	6.a.1
2	Clean[a]	Hot solution	30	175 - 180	Unspecified.	6.b.1
3	Rinse	Demineralized water		Ambient	Filtered through 10μ filter. (a) For alkaline solutions, use pH meter or transmitted light examination to determine when the alkalinity of outlet equals inlet. (b) For neutral solutions, flow a volume at least 6 times the capacity of the vessel.	6.b.5
4	Dry	Warm dry nitrogen gas			Purge until escaping gas registers a dew point of -63° F or less.	6.b.6

[a]Do not clean aluminum alloy vessels with caustic or alkaline solutions unless specifically approved.

CLEANING OF CRYOGENIC TANKS FOR LO_2, LN_2, AND LH_2 SERVICE, AIR FORCE ROCKET PROPULSION LABORATORY TECHNICAL INSTRUCTION, AFRPL TI 5-4-3, NOVEMBER 1967 (REF. 25)

Manual Cleaning

Step	Process	Agent	Time, min	Temperature, °F	Remarks	Reference paragraph
1	Preclean	Vacuum			NO SWEEPING, dust cannot be removed from the vessel.	6. a. 1
2	Clean	Unspecified solvent			Solvent if not certified must pass through 10 μ filter; in all cases surfaces shall be thoroughly wiped or scrubbed with rags or brushes.	6. a. 3
3	Rinse	Potable or demineralized water				6. a. 3
4	Pressure check	Dry nitrogen			Pressurize to operating pressure; hold 24 hours within 3 psig corrected for temperature. Closure shall not leak.	6. a. 7
5	Purge	Gaseous nitrogen			Repeatedly pressurize and dump until effluent gas smells sweet (no evidence of characteristic odors of cleaning solution used and dew point = -63° F or less).	6. a. 8. a

D. Tubing

1. Aluminum alloy tubing
2. Nonferrous pipe assemblies, tubing
3. Steel pipe, pipe assemblies, tubing

MSFC SPEC-164A (REF. 5)

Aluminum Alloy Tubing

Step	Process	Agent	Time, min	Temperature, ^oF	Remarks	Reference paragraph
1	Cleaning		10	160±10	Circulation rate at least 20 tubing or hose volumes per min.	3.5.2.6 3.5.1.6
2	Flushing	Tap water	10	Room		
3	Cleaning	3.0 - 5.0% nitric acid	5 (min) 7 (max)	85 - 95	Spec. O-N-350: Phosphoric acid solution 0.5% by wt to remove heavy soils.	3.5.2.6
4	Flushing	Demineralized water	10	Room	No particle over 175 microns, etc.	3.2.10 3.5.1.6 3.5.2.6 4.4.3.1
5	Dry					

CLEANING PROCEDURES - METALS CLEANING SPI-49.111
LINDE COMPANY, DIV. OF UNION CARBIDE, DECEMBER 28, 1965 (REF. 8)

Nonferrous Pipe Assemblies and Parts

Step	Process	Agent	Time, min	Temperature, ^oF	Remarks	Reference paragraph
1	Preclean	Diversey 1319 (1) 3 oz/gal water		Ambient	(1) Code 3008-2825; step 1 optional.	.03
2	Rinse	Hot water (2)			Remove flux; (2) water shall be potable	.03.1
3	Pickle	$Na_2Cr_2O_7$, 9 oz/gal water; H_2SO_4, 16% by volume water		Ambient	Soak until uniformly pickled.	.03.2
4	Rinse	Cold or hot water				.03.3
5	Clean	Step 1				.03.4
6	Rinse	Step 4				.03.5
7	Dry					

CLEANING PROCEDURES - METALS CLEANING SPI-49. 111
LINDE COMPANY, DIV. OF UNION CARBIDE, DECEMBER 28, 1965 (REF. 8)

Nonferrous Pipe and Tubing - Straight Lengths

Step	Process	Agent	Time, min	Temperature, °F	Remarks	Reference paragraph
1	Preclean	Diversey 1319: (1) 3 oz/gal water		Ambient	(1) Code 3008-2825.	.04. 1
2	Rinse	Cold water (2)			(2) Water shall be potable.	.04. 2
3	Pickle	$Na_2Cr_2O_2$, 9 oz/gal water; H_2SO_4, 16% by volume in water		Ambient	Soak until uniformly pickled.	.04. 3
4	Rinse	Step 2				.04. 4
5	Clean	Step 1				.04. 5
6	Dry					.04. 6

CLEANING AND TESTING OF OXYGEN AND NITROGEN GAS PIPING SYSTEMS
MIL-STD-1330 (SHIPS) MAY 10, 1968 (REF. 20)

Oxygen System Flush

Step	Process	Agent	Time, min	Temperature, °F	Remarks	Reference paragraph
1	Disassemble					5. 2. 3
2	Flush	Trichlorotrifluoroethane	30		MIL-C-81302 type I, ultraclean. Repeat flushing if more than 5 ppm total contamination is found.	5. 2. 4. 1
3	Drain					5. 3. 1. 4
4	Dry	Dry, oil-free nitrogen, air, or vacuum				5. 3. 1. 4

MSFC-SPEC-164A (REF. 5)

Corrosion-Resistant Steel Tubing

Step	Process	Agent	Time, min	Temperature, °F	Remarks	Reference paragraph
1	Cleaning	Nonetch alkaline: e.g., Turco 4215 - concentration, 10±2 oz/gal	10	160±10	Circulation rate at least 20 tubing or hose volumes of liquid per min.	3.5.1.6
2	Flushing	Tap water	10	Room		3.5.1.6
3	Cleaning	Nitric acid solution, 10±2% by wt	5 (min) 10 (max)	170 - 190	See spec. D-N-250.	3.5.1.6
4	Flushing	Demineralized water	10	Room	No particle over 175 microns; no more than 5 particles from 100 - 175 micron size; specific resistance, 50 000 Ω; pH rating between 6 and 8.	3.2.10
5	Dry					

CLEANING OF PIPING AND EQUIPMENT - SECTION 49
WHITE SANDS (REF. 6)

Piping Steel

Step	Process	Agent	Time, min	Temperature, °F	Remarks	Reference paragraph
1	Mechanical	Grinding, brushing, sandblasting (Al_2O_3 sand), vacuum clean, flushing with clean water.				49-07a
2	Degreasing[a]	Trichloroethylene or mild commercial alkaline cleaner		140 - 160	MIL-T-27602: 5 - 7 oz/gal water solvent reused until contaminant concentration reaches 0.1% by wt.	49-07b
3	Rinsing	Clean water until cleaning solvent not evident			For alkaline cleaner only.	49-07c
4	First inspection	Visual			Presence of rust, scale etc. Proceed to step 5.	49-07d
5	Chemical descaling	Solution of fluorides and HNO_3			Steel surfaces - conditions to be determined by tests on representative specimens.	49-07e
		Method A: 20% NaOH in water		140 - 160	Remove varnish from surfaces. Flush until effluent pH stabilizes between 3.0 to 4.0.	49-074

[a]Valves and accessories are to be disassembled and cleaned in accordance with this specification (49-07i). Parts, such as gaskets and seals, that might be harmed by cleaning chemicals shall be cleaned by dipping in isopropyl alcohol.

Concluded. CLEANING OF PIPING EQUIPMENT - SECTION 49
WHITE SANDS (REF. 6)

Step	Process	Agent	Time, min	Temperature, ^{o}F	Remarks	Reference paragraph
6	Passivation	(1) 0. 0. 1% citric acid (2) 0. 25 - 0. 50% NaOH solution (3) Rinse with demineralized water (4) 0. 25% monosodium phosphate, 0. 25% disodium phosphate; 0. 50% sodium nitrite; 99. 0% demineralized water	 60		Rinse with alkaline. Surface treat.	
		Method B: (1) 0. 10% Na_2CrO_4 solution (2) Rinse with demineralized water (3) Dry	15 - 20		Surface treat.	49-07f
7	Final rinse	Demineralized water			Until pH effluent = pH influent.	49-07g
8	Dry	(1) Air or (2) Vacuum evacuation		140 - 250		49-07h
9	Final dry	Purge gas		140	Until a dew point of -60^{o} F is reached.	49-07h

CLEANING, TESTING, AND HANDLING OF OXYGEN, FUEL, AND PNEUMATIC COMPONENTS D5-12855, THE BOEING CO., MAY 15, 1968 (REF. 9)

Small Tubing (1 in. i.d. max) Length to Inside Diameter Ratio Greater Than 10

[Tubing over 1 in. i.d. and with length i.d. ratio less than 10 will be processed as parts.]

Step	Process	Agent	Time, min	Temperature, °F	Remarks	Reference paragraph
1	Rough clean					5.2
2	Solvent flush	Trichloroethylene precision cleaning agent or Dowclene WR	5		Processing times given are minimum; flushing solution flow rates shall be 10 ft/sec minimum.	6.2.2
3	Alkaline flush	Turco 4215, 4215S, 4142, or 4142S or comparable nonsilicated alkaline cleaner, 1.0 - 2.0 oz/gal in water	10	150 - 170	Water distilled or deionized; minimum spec. resistance, 50 000 Ω.	6.2.3
4	Dry	Nitrogen, air, or other gas specifically approved by engineering			Shall meet 6.2.1.1; shall not contain condensable hydrocarbons in excess of 3 ppm by weight; shall not exceed 60% RH at ambient temperature.	6.2.6 or 6.2.7
5	Visual acceptance inspection					4.9
6	Final flush	Step 2	3			6.2.2
7	Dry	Step 4				6.2.6 or 6.2.7

CLEANING PROCEDURE - METALS CLEANING SPI-49. 111
LINDE CO., DIV. OF UNION CARBIDE, DECEMBER 28, 1965 (REF. 8)

Steel Pipe and Steel Pipe Assemblies and Steel Parts

Step	Process	Agent	Time, min	Temperature, ^{o}F	Remarks	Reference paragraph
1	Strip paint	Diversey aluminum: (1) 12 oz/gal of water Diversey G-60: (2) 4 oz/gal of water		165	(1) Code 3008-3000. (2) Code 3008-2770. Soak until all paint is removed or loosened.	.06.1
2	Preclean	Diversey 1319: (3) 3 oz/gal water		Ambient	(3) Code 3008-2825.	.06.2
3	Rinse	Cold or hot water (4)			(4) Water shall be potable.	.06.3
4	Pickle	Diversey Everite: 20% by volume in water	120	Ambient	(5) If solution is at 140^{o} F soak for 60 minutes. Sheet steel parts should not be soaked any longer than is necessary to remove rust and scale.	.06.4
5	Rinse	Step 3				.06.5
6	Rust proof	Oakite 87, 6 oz/gal of water	5	170		.06.6
7	Rinse	Step 3				.06.7
8	Rust proof	H_2CrO_4, 0.1 oz/gal water	2		DO NOT RINSE	.06.8
9	Dry					.06.9

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TABLE I. - CLEANLINESS REQUIREMENTS

(a) Aerospace clean category

Specification	Service	Particulate limits		Fiber limits		Condensable hydrocarbons, ppm by weight of test gas	Nonvolatile residue, mg/ft^2	Total solids, mg/ft^2	Solvent soluble organic residue, mg/ft^2
		Size, μ	no./ft^2	Length, μ	Population, no./ft^2				
MSC-SPEC-C-7	LM propellant subsystem	0 - 50 50 - 100 100 - 250 >250	Unlimited 100 4 0	NS[a]	NS	NS	1	NS	NS
	LM ECS oxygen cabin pressure	0 - 50 50 - 75 75 - 100 >100	Unlimited 100 10 0	NS	NS	NS	1	NS	NS
	RCS-CM/SM propellant subsystem	0 - 50 50 - 75 75 - 100 >100	Unlimited 100 10 0	NS	NS	NS	1	NS	NS
	SPS pressurization subsystem	0 - 50 50 - 100 100 - 200 >200	Unlimited 200 32 0	100 - 200 >200	5 0	NS	1	NS	NS
	SPS propellant system	0 - 50 50 - 100 100 - 180 180 - 350 >350	Unlimited 100 20 5 0	100 - 350 >350	5 0	NS	1	NS	NS
KSC-C-123D	LOX and fuel parts, field parts, assemblies, and subsystems (level III)	0 - 35 36 - 60 61 - 95 96 - 135 136 - 170 171 - 350 >350	Unlimited 40 10 3 2 1 0	0 - 35 36 - 350 351 - 700 >700	Unlimited 10 1 0	2	1	NS	NS
KSC (proposed)	GSE LOX and fuel systems, parts, assemblies, subsystems, etc. (level C)	<50 50 - 100 101 - 150 151 - 200 201 - 250 >250	Unlimited 69 20 9 1 0	Fibers are counted as particles; fiber size is determined by the length		1	NS	NS	1
USAF T.O. 42C-1-11	LOX component subsystem (Thor, Atlas, and Titan I)	300 - 500 501 - 1000 >1000	25 5 0	750 - 2000 2001 - 6000 >6000	50 5 0	None using black light inspection	NS	5	NS
MSFC-SPEC-164A	LOX and GOX tubing, hoses, rigid tubing, flex hose assemblies, miscellaneous components and control assemblies (onboard and GSE; see Containers)	175 - 700 701 - 2500 >2500	5 1 0	NS	NS	-------------	1	NS	NS

[a]Not specified.

TABLE I. - Continued. CLEANLINESS REQUIREMENTS

(a) Continued. Aerospace clean category

Specification	Service	Particulate limits		Fiber limits		Condensable hydrocarbons, ppm by weight of test gas	Nonvolatile residue, mg/ft^2	Total solids, mg/ft^2	Solvent soluble organic residue, mg/ft^2
		Size, μ	no./ft^2	Length, μ	Population, no./ft^2				
SDA 0-75192B	Propellant utilization system components; wipe test	[b]175 [c]175	[b]0 [c]0	>[b]2000 (c, d)	[b]0 (c, d)	No fluorescence	NS	NS	NS
Boeing Company D-5-12855	Cleaning, cleanliness testing and handling of oxygen, fuel, and pneumatic components (IOM 01671, level IV)	0 - 50 51 - 140 141 - 230 231 - 320 321 - 410 411 - 500 >500	Unlimited 40 10 3 2 1 0	0 - 50 51 - 500 501 - 1000 1001	Unlimited 10 1 0	NS	2	NS	NS
MSC-SPEC-C-7	EPS cryogenic distribution subsystem	0 - 50 50 - 100 100 - 175 >175	Unlimited 100 10 0	NS	NS	NS	1	NS	NS
	EPS cryogenic tanks	0 - 175 175 - 700 >700	Unlimited 6 0	700 - 1500 >1500	1 0	NS	1	NS	NS
GDA 0-75192B	Tanks, all components (rinse test)	300 - 500 500 - 1000 >1000	10 2 0	700 - 2000 2000 - 6000 >6000	20 2 0	No fluorescence	NS	2	NS
White Sands sec. 49	Piping and equipment	0 - 9 10 - 25 25 - 50 50 - 100 >100	Unlimited 500 15 10 0	(d)	(d)	--------------	NS	4	NS
Air Products QCL 107F	Class AAA	175 - 500 >500	25 0	>2000	0	No fluorescence	NS	NS	NS
GDA 0-75192B	Propellant utilization system components (rinse test)	[b]300 - 5000 >[b]500 [c]50 - 75 [c]75 - 100 >[c]100	[b]4 [b]0 [c]8 [c]6 [c]0	[b]1000 - 2000 >[b]2000 (c, d)	[b]2 [b]0 (c, d)	No fluorescence	NS	2	NS
	Interchangeable standard parts (rinse test)	300 - 500 >500	4 0	1000 - 2000 >2000	2 0	No fluorescence	NS	2	NS
	Contamination barrier and seal material (rinse test)	[b]300 - 500 >[b]500 [c]50 - 75 [c]75 - 100 >[c]100	[b]4 [b]0 [c]8 [c]6 [c]0	[b]1000 - 2000 >[b]2000 (c, d)	[b]2 [b]0 (c, d)	No fluorescence	NS	2	NS
	Propellant tanks (wipe tests)	>300	0	>4000	0	(d)	NS	NS	NS
	All other components (wipe tests)	>175	0	>2000	0	(d)	NS	NS	NS

[b]Nonmetallic.
[c]Metallic.
[d]None allowed.

TABLE I. - Continued. CLEANLINESS REQUIREMENTS

(a) Concluded. Aerospace clean category

Specification	Service	Particulate limits		Fiber limits		Condensable hydrocarbons, ppm by weight of test gas	Nonvolatile residue, mg/ft^2	Total solids, mg/ft^2	Solvent soluble organic residue, mg/ft^2
		Size, μ	no./ft^2	Length, μ	Population, no./ft^2				
MSC-SPEC-C-11A	Pressurization systems, reaction control propellant systems	0 - 5 5 - 15 15 - 25 25 - 50 50 - 100 >100	Unlimited 170 100 40 20 0	NS	NS	NS	1	NS	NS
	Electrical power systems	0 - 10 10 - 25 25 - 50 50 - 100 100 - 175 >175	Unlimited 100 10 5 1 0	NS	NS	NS	1	NS	NS
	Small propulsion systems	0 - 5 5 - 15 15 - 25 25 - 50 50 - 100 100 - 250 >250	Unlimited Unlimited Unlimited 2100 100 4 0	NS	NS	NS	1	NS	NS
	Main propulsion systems	0 - 25 25 - 50 50 - 100 100 - 180 180 - 350 >350	Unlimited 1000 100 20 5 0	350 >350	5 0	NS	1	NS	NS
NASA FRC process spec. 20-1	LOX components, breathing oxygen components	10 - 26 26 - 100 100 - 750 750 - 1500 1500	[e]Unlimited (6000) [e]13 250 (250) [e]265 (5) [e]53 (1) [e]0 (0)	NS	NS	NS	NS	NS	NS
MSC-SPEC-C-9A	Nonairborne breathing systems	0 - 175 175 - 700 >700	Unlimited 6 0	700 - 1500 >1500	1 0	---	1	NS	NS
MSC-SPEC-C-11A	Environmental control systems	0 - 175 175 - 700 >700	Unlimited 6 0	700 - 1500 >1500	1 0	NS	1	NS	NS
LeRC RDL-003	LOX and GOX components (Plum Brook Station)	5 - 50 51 - 100 101 - 150 151 - 350 >350	Unlimited 40 18 5 0	0 - 500 501 - 1000 1001 - 1875 >1875 (up to 25 diam)	20 3 1 0	0	NS	2.5	NS
GDA 0-75192B	Transducers, surface area of 1 ft^2 or greater	300 - 500 >500	4 0	>2000	0	No fluorescence	NS	NS	NS
	Transducers, surface area of less than 1 ft^2	300 - 500 >500	2 0	>2000	0	No fluorescence	NS	NS	NS

[e]Extrapolated from 47 mm diam filter paper count; parentheticals are actual values.

TABLE I. - Concluded. CLEANLINESS REQUIREMENTS

(b) Commercial clean category

Specification	Service	Particulate limits		Fiber limits		Condensable hydrocarbons, ppm by weight of test gas	Nonvolatile residue, mg/ft^2	Total solids, mg/ft^2	Solvent soluble organic residue, mg/ft^2
		Size, μ	no./ft^2	Length, μ	Population, no./ft^2				
Linde Division's oxygen		NS (10 mg)		NS	NS	NS	500	NS	10
Air Products QCL 105F	Class A	750 - 1500 >1500	10 0	6000	0	Low intensity fluorescence acceptable	---	---	---
Air Products QCL 106F	Class AA	500 - 1000 >1000	10 0	2000	0	No fluorescence, isolated particle of lint acceptable	---	---	---

TABLE II. - GENERAL DESCRIPTION OF CLEANING PROCEDURES

Cleaning step	Cleaning agent	Method	Purpose
Preclean	Trichloroethylene, trichlorotrifluoroethane, mixtures of nitric and hydrofluoric acid, compressed air	Soak, brush, blow, spray, dip, shot peening, vapor degrease	Remove gross contamination such as scale, slag, rust, surface adhering soils, greases, oxides
Clean	Trichloroethylene, trichlorotrifluoroethane, mixtures of nitric and hydrofluoric acid, alkaline cleaning agents, phosphoric acid organic solvent mixtures, detergent solutions	Soak, brush, apply ultrasonic energy, dip, soak, spray, flush, vapor degrease, mechanical washers	Remove soils, greases, fibers, particulate matter in precision cleaning operations; remove fine contaminants
Rinse	Tap water, demineralized water, distilled water, alcohol, trichloroethylene, trichlorotrifluoroethane, methylene chloride	Soak, brush, apply ultrasonic energy, dip, soak, spray, flush, mechanical washers	Remove detergent or solvent solutions
Inspect		Visual, ultraviolet light, water break, flood light, pH paper, solvent brush, wipe test, gas blowdown, nonvolatile residue, solvent soluble organic residue, condensable hydrocarbon	Determine and/or verify the level of cleanliness attained during cleaning process
Dry	Dry, filtered air, nitrogen, heat, vacuum	Mechanical: Dry, filtered air or nitrogen blowoff Thermal: Ovens, vacuum ovens	Remove last remnants of rinse solvents

TABLE III. - EFFECTS OF COMMON

Cleaning solvent	Federal or MIL specification	Plastics			
		Polystyrene	Polyvinyl chloride	Polyethylene	Bakelite (phenolic)
					Chlorinated
Methylene chloride (dichloromethane, technical)	MIL-D-6998A-1 Grade A - 0.005% max acidity Grade B - 0.010% max acidity	Dissolves	Will damage	Will damage on prolonged contact	None
Trichloroethylene, technical	O-T-634a Type I - Regular Type II - Stabilized for vapor degreasing (Supersedes MIL-T-7003)	Dissolves	4 hr - swollen	4 hr - slight effect	None
1, 1, 1-trichloroethane (inhibited methyl chloroform, technical inhibited)	O-T-620a-2 (Supersedes Safety Solvent) MIL-S-18718(Aer)-1 which consistec of 70% mineral spirits, 25% methylene chloride, 5% perchloroethylene)	Dissolves	1 hr - none 4 hr - slight swell	1 hr - none 4 hr - slight swell	None
Carbontetrachloride (tetrachloromethane, technical grade)	O-C-141 (Cancelled)	Dissolves	5 min - none	5 min - slight swell	None
Blend of chlorinated solvents (composition proprietory)		Dissolves	10 min - none	1 hr - none 4 hr - slight swell	None
Perchloroethylene (tetrachloroethylene, technical grade)	O-T-236a (Supersedes O-P-191a)	Dissolves on long	4 hr - none	4 hr - slight effect	None
					Aromatic
Benzene (benzol, technical)	VV-B-231c Grade A - Industrial-grade benzene Grade B - Industrial-90 benzene	Dissolves			
Toluene (toluol, technical)	TT-T-548c	Dissolves			
Xylene (xylol)	TT-X-916b	Dissolves			
Naptha (distilled from petroleum, aromatic)	TT-N-97b Type I - Boiling range (190° - 284° F) Grade A - high solvent power Grade B - low solvent power Type II - Boiling range (265° - 376° F) Type III - Boiling range (340° - 425° F)				

[a]Effects data determined by Sandia Laboratory, Albuquerque, New Mexico.

Effect on materials of construction[a]								
Elastomers			Wire coatings, insulating varnishes, and marking inks					
Teflon (TFE)	Neoprene rubber	Silicon rubber	Formvar polyvinyl formal	Bondar	Glyptal 1201 (air-dried)	Glyptal 1202 (air-dried)	GE 9740 (baked)	Ink
hydrocarbons								
None	Swells	Swells	Severe crazing	Slight effect	Lifted	Lifted	Lifted	Removed
None	Swells	Swells	Will soften	None	Lifted	Lifted	Lifted	Removed
None	3 min - none 5 min - slight swell	3 min - none 5 min - swell	5 min - none	5 min - none	5 min - none	5 min - lifted	5 min - lifted	Some removed (will not remove epoxy-based ink)
None	5 min - swell	Swells	Slight effect	None	Slight effect	Slight effect	Slight effect	Partially removed
None	5 min - slight swell	Swells	5 min - none	5 min - none	5 min - none	5 min - lifted	5 min - lifted	Partially removed
None	Swells on prolonged contact	Swells	None	None	None	Slight effect	Slight effect	Partially removed
petroleum								
	Dissolves							
	Dissolves		1 hr - softened					
			1 hr - solvent discolored indicating resin extraction					

TABLE III. - Concluded. EFFECTS OF COM

Cleaning solvent	Federal or MIL specification	Plastics			
		Polystyrene	Polyvinyl chloride	Polyethylene	Bakelite (phenolic)
Fluorinated					
Trichloromonofluoromethane (fluorocarbon 11) (solvent grade)		Dissolves on long exposure	Slight effect	Slight effect	None
Trichlorotrifluoroethane (fluorocarbon 113) (solvent grade)	MIL-C-81302 Wep (Covers Freon PCA and equivalent grade solvents; is being revised to also cover Freon TF and equivalent grade solvents)	4 hr at 75° F - none 4 hr boiling - cracked and brittle	4 hr - none	4 hr - none	None
Aliphatic					
Naptha, aliphatic (petroleum naptha)	TT-N-95a Type I - For organic coating Type II - For cleaning acrylic plastics				
Stoddard solvent (dry cleaning solvent)	P-D-680 (Supersedes P-S-661b) Type I - 100° F min flashpoint Type II - 140° F min flashpoint	5 min - none	None	None	
Mineral spirits Thinner; paint, volatile spirits (petroleum spirits)	TT-T-291c Grade 1 - Light thinner Grade 2 - Heavy thinner				
Oxygenated					
Isopropyl alcohol (anti-icing fluid and solvent)	TT-1-735o (Supersedes MIL-F-5566 and MIL-1-10428A) Grade A - 0.1% max water; for use in manufacturing Grade B - 0.4% max water; for use as antiicing fluid and solvent	5 min - none	5 min - extracts plasticizer	None	None
Methyl alcohol (methanol)	O-M-232d Grade A - 99.8% synthetic (solvent use) Grade AA - 99.8% synethetic (H-CO_2 generators) Grade B - 99% technical (solvent use) Grade C - wood alcohol (denaturing grade)	5 min - none	5 min - extracts plasticizer	None	None
Ethyl alcohol (ethanol)	O-E-760b (Supersedes O-A-396)	5 min - none	5 min - extracts plasticizer	None	None
Acetone, technical	O-A-51d	Dissolves	Dissolves	None	Dissolves

[a]Effects data determined by Sandia Laboratory, Albuquerque, New Mexico.

MON CLEANING SOLVENTS ON MATERIALS

Effect on materials of construction[a]								
Elastomers			Wire coatings, insulating varnishes, and marking inks					
Teflon (TFE)	Neoprene rubber	Silicon rubber	Formvar polyvinyl formula	Bondar	Glyptal 1201 (air-dried)	Glyptal 1202 (air-dried)	GE 9740 (baked)	Ink
hydrocarbons								
None	Slight swell	Slight swell						
None	1 hr - none	1/2 hr - 6% swell	100 hr - none	100 hr - none	Unknown	Unknown	Unknown	None
petroleum								
None	None	None	None	None	None	None	None	None
solvents[a]								
None	None	None	None	5 min - none	5 min - none	5 min - none	10 min - none	Varies with ink
None	None	None	None	5 min - none	5 min - none	5 min - none	10 min - none	Varies with ink
None	None	None	None	5 min - none	5 min - none	5 min - none	5 min - none	Varies with ink
None	Swells	Extracts plasticizer	None	5 min - none	Dissolves	Dissolves	Dissolves	Removes

TABLE IV. - CLEANING PROCEDURES

Step	Process	Aerospace clean category				
		KSC (proposed, ref. 11) CRES (pickling required)	KSC (proposed, ref. 11) CRES (pickling not required)	KSC (proposed, ref. 11) CRSE (cleaning in field)	T.O. 42C-1-11 (ref. 12) 400 Series stainless and free machining grade 300 series parts	T.O. 42C-1-11 (ref. 12) 300 Series stainless steel except free machining parts
1	Mechanical descale or preclean	Brushing, shot peening, etc.	Brushing, shot peening, etc.	12±0.5% of 61% HNO_3 by volume; 1.5±0.05% of 48% HF by volume; balance is deionized H_2O for 15 - 60 min at ambient	Mechanical descaling	Mechanical descaling
2	Solvent and/or vapor degrease	Trichloroethylene or trichlorotrifluoroethane	Trichloroethylene or trichlorotrifluoroethane		Solvent degrease-trichloroethylene and vapor degrease trichloroethylene or trichlorotrifluoroethane	Degrease trichloroethylene and vapor degrease trichloroethylene or trichlorofluoroethane
3	Dry	Gaseous N_2	Gaseous N_2			
4	Detergent grease	0.5% detergent solution MIL-D-16791 and deionized H_2O for 5 - 15 min at 110° - 130° F				
5	Rinse	H_2O for 5 min at 90° - 110° F				
6	Pickle	12±0.5% of 61% HNO_3 1.5±0.5% of 48% HF in deionized H_2O for 15 - 60 min at ambient				
7	Rinse	H_2O for 5 min at 90° - 120° F				
8	Rinse	Deionized H_2O for 3 min				
9	Dry	Gaseous N_2 at 120° - 140° F				
10	Clean	5±0.5% of 85% H_3PO_4; 10±0.5% of 2-butoxyethanol solvent, 0.5±0.05% surfactant; balance is H_2O for 30 - 120 min at 80° - 105° F.	5±0.5% of 85% H_3PO_4; 10±0.5% of 2-butoxyethanol solvent; 0.5±0.05% surfactant; balance is H_2O for 30 - 120 min at 80° - 105° F	5±0.5% of 85% H_3PO_4, 10±0.5% of 2-butoxyethanol solvent; 0.5±0.05% surfactant; balance is H_2O for 60 - 120 min at 85° - 105° F	Alkaline cleaner (Fed. Spec. P-C-436): 5 - 10 oz/gal of tap H_2O for 15 - 25 min at 150° - 175° F	Alkaline cleaner (Fed. Spec. P-C-436): 5 - 10 oz/gal of tap H_2O for 15 - 25 min at 150° - 175° F
11	Rinse	H_2O for 5 min at 90° - 110° F	H_2O for 5 min at 90° - 110° F	Deionized H_2O for 30 min at ambient	Detergent solution (Fed. Spec. P-C-437): 1/2 - 1 oz/gal of tap H_2O or demineralized H_2O for 15 - 25 min at 120° - 140° F	Detergent solution (Fed. Spec. P-C-437): 1/2 - 1 oz/gal of tap H_2O for 15 - 25 min at 120° - 140° F
12	Rinse	Deionized H_2O for 3 min	Deionized H_2O for 3 min		Tap H_2O for 5 - 10 min at 150° F	Tap H_2O for 5 - 10 min at 150° F
13	Passivate pickle	15±0.5% of 61% HNO_3 by volume; balance is deionized H_2O for 15 - 60 min at ambient	15±0.5% of 61% HNO_3 by volume; remainder is deionized H_2O for 15 - 60 min at ambient		12% HNO_3 by volume; 1% HF by volume; balance is tap H_2O *for 10 min at 60°* - 100° F	20% HNO_3 by volume; 3% HF by volume; tap H_2O for *15 min at 60°* - 100° F
14	Rinse	H_2O for 5 min at 90° - 110° F	H_2O for 5 min at 90° - 110° F		Tap H_2O for 5 - 7 min at 150° F	Tap H_2O for 5 - 7 min at 150° F
15	Rinse	Deionized H_2O for 5 min	Deionized H_2O for 5 min		Demineralized H_2O for 5 - 10 min at 150° F	Demineralized H_2O for 5 - 10 min at 150° F
16	pH test	Narrow range pH paper (pH = 6.0 - 8.0)	Narrow range pH paper (pH = 6.0 - 8.0)	pH paper sensitive to each 0.1 pH unit (pH = 6.0 - 8.0)		
17	Dry	Gaseous N_2 at 120° - 140° F	Gaseous N_2 at 120° - 140° F	Gaseous N_2 to dew point (-65° F)	Oven at 180° - 200° F; gaseous N_2 at 140° F vacuum	Oven at 160° - 200° F; gaseous N_2 at 140° F vacuum
18	Rinse			*Trichloroethylene or tri-*chlorotrifluoroethane (30 min)	*Detergent solution (MIL-D-*16791 type I): 1/2 - 1 oz/gal tap of or demineralized H_2O or trichloroethylene (150° F) for 15 - 25 min at 120° - 140° F	*Detergent solution (MIL-D-*16791 type I): 1/2 - 1 oz/gal H_2O for 15 - 25 min at 120° - 140° F or trichloroethylene
19	Flush final clean	Trichlorotrifluoroethane	Trichlorotrifluoroethane, 1 min		Demineralized H_2O at 150° F; omit if solvent used in step 18	Demineralized H_2O at 150° F; omit if solvent used in step 18
20	Inspect	Verify cleanliness	Verify cleanliness			
21	Dry	Gaseous N_2 at 120° - 140° F vacuum	Gaseous N_2 at 120° - 140° F vacuum	Gaseous N_2	Oven at 180° - 200° F; gaseous N_2 at 140° F vacuum	Oven at 180° - 200° F; gaseous N_2 at 140° F vacuum

FOR VARIOUS STEELS

			Commercial clean category		
CPIA publication 194 Stainless steel tanks (ref. 21)	CPIA publication 194 Stainless steel components (ref. 21)	Plum Brook RDL-003 Stainless steel (ref. 3)	Linde SPI-49. 111 Steel and stainless shells (ref. 8)	Linde SPI-49. 111 Stainless steel (ref. 3)	Linde SPI-49. 111 9% nickel and stainless steel heads (ref. 8)
Mechanical descaling or HNO_3 mixture					Diversey 1319 3 oz/gal H_2O at ambient
Solvent	Perchloroethylene	Trichloroethylene or detergent water solution			
				Cold H_2O	
				4% HF by volume; 14% HNO_3 + H_2O; 145° F	
Alcohol	Alcohol				
H_2O or steam	H_2O	Distilled or deionized H_2O		Cold, potable H_2O	Cold potable H_2
				Dry air or N_2	Dry air or N_2
4% detergent for 30 min at 150° F	4% detergent solution for 30 min at 120° F	3 - 5% by volume HF; 35 - 45% technical grade HNO_3 and deionized H_2O	Diversey 1319 3 oz/gal H_2O at ambient		
	H_2O				
	40 - 50% HNO_3 bath for 60 min				
		Deionized H_2O pH effluent = pH influent	Potable H_2O		
Particle free, deionized H_2O	Steam				
N_2	Gaseous N_2	Hydrocarbon free, gaseous N_2	Gaseous N_2 or air		

TABLE V. - CLEANING PROCEDURES FOR ALUMINUM

Step	Process	Aerospace clean category				Commercial clean category	
		KSC (proposed) aluminum	KSC (proposed) in field aluminum cleaning by solution spray (ref. 11)	Boeing Aircraft Co. DS-12855, May 15, 1968; aluminum (ref. 9)	CPIA Publication 194 October 20, 1970; aluminum and aluminum alloys (ref. 21)	T. O. 42C-1-11 (ref. 12)	Linde Co. SPI-49. 111 December 28, 1965; aluminum (ref. 8)
1	Rough cleaning	Brushing, shot peening, etc.		Clean per BAC 5765. Not to be subjected to temperatures exceeding 130° F		As required mechanical descaling	
2	Preclean or degrease	Trichloroethylene or trichlorotrifluoroethane	Trichloroethylene or trichlorotrifluoroethane (5 min, 110° F) or 0. 5% detergent solution (15 min, 130° F)	Trichloroethylene, precision cleaning agent or Dowclene WR	Perchloroethylene for 30 min	Trichloroethylene	Diversey 1319, 3 oz/gal; H_2O at ambient
3	Dry	Gaseous N_2					
4	Remove corrosion	Formula V, 10 - 60 min at ambient				Vapor degrease with trichloroethylene or trichlorotrifluoroethane	
5	Rinse	H_2O for 5 min at 90° - 110° F			Alcohol		
6	Rinse	Deionized H_2O for 3 min			H_2O		Cold or hot potable H_2O
7	Dry	Gaseous N_2 at 120° - 140° F					
8	Clean	Formula V, 30 - 120 min at 80° - 95° F	Formula IV for 60 - 120 min at 80° - 95° F	Ultrasonic and detergent water solution for 5 min at 130° F max	4% solution of aluminum cleaner	Sodium carbonate, 3 oz/gal; trisodium phosphate, 3 oz/gal; balance is tap H_2O for 1 - 3 min at 140° - 180° F	Diversey aluminux, 6 oz/gal H_2O. Diversey, 2 oz/gal H_2O for 1 - 2 min at 160° F

9	Rinse	H_2O for 5 min at 90° - 110° F				Tap H_2O at 150° F	
10	Rinse	Deionized H_2O for 3 min	Deionized H_2O for 30 min	Ultrasonic and distilled or deionized H_2O for 5 min			Hot H_2O
11	Brighten/ passivate	Formula V for 10 - 60 min at ambient	Formula V for 20 - 40 min at ambient			HNO_3, 12% by volume; HF, 1% by volume, balance tap H_2O at ambient	Diversey 596, 7 oz/gal; H_2SO_4, 7% by volume; rest, H_2O at ambient
12	Rinse	H_2O for 5 min at 90° - 110° F	Trichloroethylene or trichlorotrifluoroethane (5 min at 110° F); or 0.5% detergent solution (15 min at 130° F)			Demineralized H_2O at 150° F	
13	Rinse	Dionized H_2O for 3 min	Dionized H_2O for 30 min at ambient		H_2O		Hot H_2O
14	Dry			Gaseous N_2		Oven, 180° - 200° F; or nitrogen, 140° F; or vacuum	
15	Inspect	Narrow range (6.0 - 8.0) pH paper	Narrow range (6.0 - 8.0) pH paper	Visually			
16	Dry	Gaseous N_2	Gaseous N_2				Gaseous N_2
17	Final flush or final clean	Trichlorotrifluoroethane	Trichloroethylene or trichlorotrifluoroethane	Trichloroethylene, precision cleaning agent or, Dowclene WR	Steam	Detergent solution: 1/2 - 1 oz/gal tap or demineralized H_2O or trichloroethylene; if solution used rinse with demineralized H_2O at 150° F	
18	Inspect	Analysis of solvent from step 17	Analysis of solvent from step 17				
19	Dry	Gaseous N_2	Gaseous N_2	Gaseous N_2, air, or other gas specifically approved	Gaseous N_2	Oven 180° - 200° F, or nitrogen gas at 140° F, or vacuum	

TABLE VI. - CLEANLINESS VERIFICATION TECHNIQUES

Test	Test method	Results		Reference specifications
		Characteristic results	Test limitations	
		Direct determination methods		
pH paper	All surfaces that have been cleaned shall be tested for acidity and alkalinity with narrow-range pH paper while surfaces are wet from final water rinse. Dry surfaces may be wet with few drops of distilled water to permit testing as required. Narrow range pH paper is sensitive to each 0.1 pH unit change.	pH range from 6.0 to 8.0. pH value outside specified range will cause rejection and subsequent recleans or rerinses.	1. Difficult to ascertain small color changes. 2. Very qualitative. 3. Not representative of the overall system.	KSC-C-123(D) KSC Proposed MSC-SPEC-164A
Wipe	Wipe test shall be made on interior surface of each component using new, clean filter paper (Whatman No. 42, S and S 602, or Whatman No. 44, or equal). This test shall consist of at least two movements of the filter paper across 1 ft^2 of surface.	Filter papers shall be examined under microscope for particulate contamination and under ultraviolet light for fluorescence. Failure to conform with cleanliness requirements will cause rejection, reclean, and reinspection.	1. Very qualitative. 2. Not truly representative of cleanliness where accessibility is limited. 3. Subject to operator errors. 4. Questionable reproducibility.	USAF T.O. 42C-1-11 AFRPL-TI-No. 5-1-5 RDL-003 Linde SPI-49.117 GDA 14170 Air Products
Visual: Ultraviolet or black light	Surfaces to be in contact with service medium shall be visually examined using flash light, mirrors, borescope, or ×10 magnifying glass for evidence of corrosion, moisture, scale, direct grease, oil, paints, preservatives, metal chips, weld scales, and other foreign matter.	Presence of visible contamination causes rejection. Surface discoloration due to welding or passivation permitted provided no scale or other objectionable film remains. Widely used.	1. Unaided by magnifying glass visual examination limited to 40μ smallest particle detection. 2. Subjective test. 3. Most effective with particulate matter. 4. Least effective with invisible films. 5. Highly trained microscopist may increase validity of test results. 6. Highly qualitative.	USAF T.O. 42C-1-11 KSC-C-123D KSC Proposed AFRPL-TI-5-1-5 RDL-003 Linde SPI-49.117 GDA-14170 MSFC-SPEC-164A Air Products
	Visual inspection with aid of ultraviolet light source 2500 to 3700 A shall be accomplished on all accessible surfaces to determine presence of petroleum-type hydrocarbons. Ultraviolet source (3200-3800 Å) may also show some glow or fluorescence because of presence of fibers, grease, oil, and other foreign materials not visible in ordinary light.	Presence of fluorescence causes rejection.	1. Very qualitative. 2. Animal oils such as fish oil rust preservatives will not fluoresce. 3. Vegetable oils such as caster oil-based cutting emulsions will not glow. 4. Extent of contamination detectable: $<$50 ppm - not discernable. 50-100 ppm - barely discernable. $>$100 ppm - definitely discernable.	USAF T.O. 42C-1-11 MIL-STD-1330 (SHIPS) AFRPL-TI-No. 5-1-5 RDL-003 Linde SPI-49.117 GDA 14170 Air Products
Water break	Wet surface with clean water or observe receding water film as water drains off part.	Water film if unbroken for 5 seconds is indicative of cleanliness.	1. Qualitative test. 2. Contaminants in water lessen sensitivity. 3. Test limited to horizontal surfaces only. 4. Use of deionized water and a trained inspector may increase sensitivity to one molecular thickness of contaminant.	AFRPL-TI-No. 5-1-5 Linde SPI-49.117
Flood light	High-tensity light source (200 W or better) shining at oblique angle to determine particulate contamination. Dust or lint when viewed from outside bright light becomes visible.	For aerospace application, presence of lint or dust causes rejection. For commercial applications, small amounts of particulate contamination are acceptable.	1. Very qualitative. 2. Inspector dependent. 3. Of limited applicability.	AFRPL-TI-No. 5-1-5 Air Products
		Indirect determination methods		
Gas blowdown	Use a blowhorn or similar device to hold millipore filter disk (0.45±0.02 μ pores, 47 mm diameter, while 3.08 mm grid, capable of filtering 80 cc of distilled water per square centimeter per minute at 70 cm of mercury ≈ 13.5 psia at ±25° C). Flow a minimum volume of 100 SCF of gas through test item at minimum flow rate of 35 SCFM, or at normal system operating flow rate is 3 SCRM or less, total volume of test gas used may be reduced to 35 SCF. Critical surface area shall be calculated to nearest 0.1 ft^2.	Stain on filter membrane, evidence of fluorescence of particles exceeding maximum size and count criteria, or exceeding criteria by actual count will cause reclean and reinspection of test item. Second failure of item to meet particulate requirements of applicable cleanliness level will cause rejection of item.	1. Very qualitative. 2. Indicative of lack of sufficient cleanliness, but not achieved cleanliness. 3. Contaminants may not volatalize sufficiently into gas stream to provide detectability.	KSC Proposed FRC P.S. 20-1

TABLE VI. - Continued. CLEANLINESS VERIFICATION TECHNIQUES

Test	Test method	Results		Reference specifications
		Characteristic results	Test limitations	
Solvent flush	100 - 500 ml of representative flushing fluid for each square foot of critical surface area is filtered through 45 μ, type HA white grid, 47 mm diameter membrane filter. Particles are counted or estimated using ×45 magnification for particles larger than 2.5 μ and ×90 magnification for particles 25 μ or smaller. Estimates of heavily soiled are made by (1) Counting number of particles on 20 randomly selected grid squares and multiplying number by 5. (Method applicable for a given particle size estimated to be between 50 and 1000.) (2) For estimated particle count between 1000 and 5000, count number of particles on 10 randomly chosen grid squares, multiplying number by 10 to obtain total statistical count. (3) For estimated particle count exceeding 5000 in a given particle size range, particles are counted on 10 or more randomly selected grid squares. Total statistical count is arrived at by the formula $P_t = N_t \frac{E}{nA_f}$ N_t total number of particles counted in n unit areas E 960 mm^2, total effective filter area n number of unit areas counted A_f 3.08 L, unit area, mm^2 L calibrated length of ocular micrometer, mm	If particle count in a given size range as listed in table I or figures 2 through 7 is exceeded, part, system or item is rejected and submitted to additional cleaning, rinsing and inspections.	1. Qualitative test. 2. Variable reproducibility. 3. Accuracy dependent upon technician doing the counting. 4. Extremely vulnerable to error. 5. Laboratory technicians must be trained until they are able reproducibly to count standard filters.	USAF T.O. 42C-1-11 KSC Proposed FRC P.S. 20-1 MIL-STD-1330 (SHIPS) AFRPL-TI-No. 5-1-5 RDL-003 GDA 14170 MSFC-SPEC-164A
Solvent soluble organic residue	Use a precision cleaned hypodermic syringe to transfer test fluid sample and reference standard to respective infrared sealed cells with sodium chloride windows. Nominal cell path length is 3 mm for single beam infrared spectrophotometer record absorption of reference standard at 3.42 μ (2924 cm^{-1}) as A and for test sample as B. For double beam IR spectrophotometer insert reference and test sample and record net absorption at 3.42 μ for test sample as C. Calculate absorbance $\log_{10} \frac{Io}{I}$ of A, B, and C. By standard infrared baseline method (ASTM E168-64T, sec. 6) refer to previously prepared reference standard curve to obtain milligrams of solvent soluble organic residue per milliliter of solvent. Calculate per methods in results column.	Calculated SSOR/ft^2 of critical area: 1. Single beam mg/ft^2 = $\frac{(F)(E - D)}{G}$ D mg SSOR/ml (ref. std.) (calculated from A) E mg SSOR/mp test sample (calculated from B) E - D net concentration of test solvent, mg SSOR/ml F total volume of test solvent, ml G total area of critical surface tested, ft^2 2. Double beam mg/ft^2 = $\frac{(F)(H)}{G}$ F total volume of test solvent used, ml H concentration of test solvent, mg SSOR/ml (calculated from C) Exceeding the allowable limits in table I shall cause the item to be recleaned.	1. Assumes any organic material remaining on critical surface will be soluble in solvent. 2. Quantitative measurement. 3. Commercial clean does not specify of IR spectrometer.	KSC Proposed USAF T.O. 42C-1-11 (reference test only) AFRPL-TI-No. 5-1-5 (referee test only) RDL-003 (referee test only) Linde SPI-49.117 GDA 14170 (referee test only)

TABLE VI. - Concluded. CLEANLINESS VERIFICATION TECHNIQUES

Test	Test method	Remarks		Reference specifications
		Characteristic results	Test limitations	
Condensable hydrocarbons	Spectrograde CCl_4 is distilled and IR spectrophotometrically examined for hydrocarbon impurity absorbance at 3.42 μ (2924 cm^{-1}). There will be no absorbance at above bandhead. Absorption will cause CCl_4 redistillation. Using this CCl_4 and standard hydrocarbon mixture (90% by wt U. S. P. heavy white mineral oil and 10% by wt reagent grade triolein (glycerol trioleate - $(C_{17}H_{33}COO)_3C_3H_5$) reference standard absorption curve will be prepared. Three gas washing bottles (250 ml capacity) properly cleaned shall be charged with 150 ml or redistilled CCl_4, sealed at top, and interconnected with appropriate tubing to allow passage of test gas. Gas flow is measured by wet test gas meter downstream of third gas washing bottle. Record barometric pressure, wet test gas meter temperature at beginning and end of test. Adjust gas flow rate to 5 - 6 liters per minute. Allow 600 liters of test gas to flow through bottles without blowing CCl_4 from one bottle to another or reduced in volume. Upon completion, quantitatively transfer CCl_4 to beaker and evaporate to 2 ml. Transfer to 5 ml volumetric flask and dilute it to volume. Determine IR absorbance and from reference standard curve obtain milligrams of condensable hydrocarbons.	1. Total condensable hydrocarbons: $A = \frac{(B)(C)(1.54)}{1000}$ A total condensable hydrocarbons B mg condensable hydrocarbon/ml CCl_4 C total volume CCl_4 1.54 compensating evaporation factor 2. Condensable hydrocarbons, ppm by wt $D = \frac{(E)(F)(273.1)}{(760)(273.1 + G)}$ D volume test gas, liters as STP E volume test gas, liters F barometric pressure, mm Hg G average wet test gas meter temperature, $^{\circ}C$ 3. $H = (D)(I)$ H wt of test gas, g I density of test gas, g/liter 4. $J = \frac{A \times 10^6}{H}$ J condensable hydrocarbons (in ppm by wt of test gas) A total condensable hydrocarbons in 1 above. Failure to meet requirements in table I results in rejection.	1. Use of "fudge" factor can cause erroneous results: Hydrocarbon evaporation coefficient is not characteristic property and varies with experimental conditions 2. Hydrocarbons may not be volatile enough to produce detectability. 3. Process routine is sufficiently difficult to result in aborted test. 4. Test is not representative of system cleanliness. 5. IR procedure is highly quantitative, but sampling and sample treatment is highly susceptible to errors. 6. To prevent CCl_4 from backing up or spilling while replenishing it during test requires manual dexterity; lack of which affects reproducibility and accuracy of the test.	KSC-C-123(D) KSC Proposed
Nonvolatile residue	Transfer 500 ml (some procedures specify 100 ml, other procedures specify 1000 ml) into a clean degreased beaker. Evaporate solvent to 10 - 20 ml volume in steam bath. Transfer solvent to constant weight (within 0.3 mg) tared 30 ml weighing bottle, weighed to nearest 0.1 mg. Continue evaporation to volume of 5±0.5 ml. Do not let solvent evaporate to dryness. Place weighing bottle in constant temperature oven at 221° - 230° F for 1.5 hours. Cool weighing bottle in desiccator and then weigh to nearest 0.1 mg. Return weighing bottle to constant temperature oven for 0.5 hour. Repeat weighing. If difference between successive weighings is >0.3 mg, repeat drying until difference is <0.3 mg or evaporate solvent to dryness being careful not to overheat or bake residue. Cool residue and weigh to constant weight.	Test results are compared to tared blank. Difference between weights shall not exceed specified limits of contamination; otherwise, test item will be recleaned and reinspected.	1. Semiquantitative. 2. Low sensitivity. 3. Low accuracy. 4. Hydrocarbon evaporation coefficient varies with experimental conditions and is not characteristic property. 5. Solvents contain stabilizers which contribute to erroneous results. 6. Tedious procedure requiring laboratory to be carried out. 7. Laboratory manipulations can result in loss of hydrocarbons.	USAF T.O. 42C-1-11 KSC-C-123(D) KSC Proposed AFRPL-TI-No. 5-1-5 Linde SPI-49.117 MSFC-SPEC-164A Air Products

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